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SAN FRANCISCO VESSEL TRAFFIC SYSTEM COMPARISON TESTS OF THE RAYTHEON 1605 HARBOR ADVISORY RADAR WITH THE AN/FPS-109(XN-1) VESSEL TRAFFIC SYSTEM RADAR

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A comparison test was conducted to determine the capabilities and the performance of the Raytheon 1605 Harbor Advisory Radar (HAR) and the AN/FPS-109(XN-1) Vessel Traffic System (VTS) surveillance radar. It was concluded that the FPS-109 radar is superior to the HAR radar in all areas of performance and operational flexibility; however, the HAR radar is an older radar system with fewer built-in functions and was not operating within its rated performance envelope.

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UNITED STATES COAST GUARD
ENVIRONMENTAL AND TRANSPORTATION
TECHNOLOGY DIVISION REPORT

SAN FRANCISCO VESSEL TRAFFIC SYSTEM COMPARISON TESTS OF THE RAYTHEON 1605 HARBOR ADVISORY RADAR WITH THE AN/FPS-109 (XN-1) VESSEL TRAFFIC SYSTEM RADAR

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ABSTRACT

A limited comparison test was conducted to determine the improvement in surveillance capability between an existing Harbor Advisory Radar (HAR) and a prototype AN/FPS-109(XN-1) radar designed specifically for harbor surveillance. The FPS-109 radar is clearly superior in all areas of performance and operational flexibility. However, the HAR is an older radar system that was not operating within its rated performance envelope.

SUMMARY

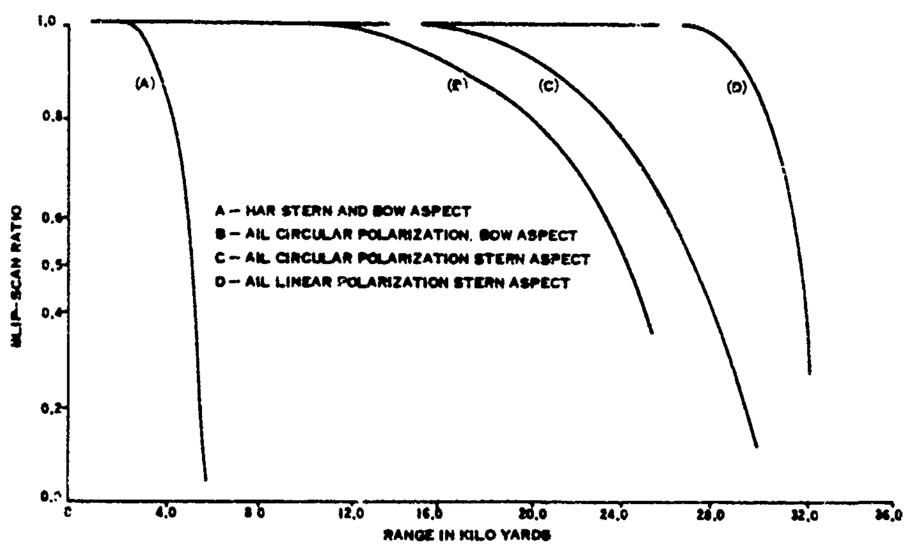
During the period from 6 February to 16 February 1978, a series of performance comparison tests were made on the AN/FPS-109(XN-1) Vessel Traffic System (VTS) surveillance radar manufactured by the Airborne Instrument Laboratories, and hereafter referred to as the AIL radar, and the Harbor Advisory Radar (HAR) manufactured by the Raytheon Corporation. Both of these radars are installed at Yerba Buena Island (YBI) in the San Francisco Bay area. A second Airborne Instrument Laboratories (AIL) radar is installed at Point Bonita (PTB). The purpose of the test was to obtain comparative data for the AIL and HAR radars while they were tracking the same target simultaneously. The primary emphasis of the test was placed on obtaining quantitative data on the maximum detection range capabilities, the angle resolution capabilities, and the range resolution capabilities of both radars. Secondary emphasis was placed in the areas of operator assist features such as the use of the fast time constant (FTC) and sensitivity time control (STC), which are available in both radars, and circular polarization, which is available in the AIL radar. These features are used in reducing target masking effects of rain and sea clutter return on the plan position indicator (PPI) display.

Prior to the commencement of the test, both radar systems were checked by representatives of the manufacturers of the respective systems. Limited repairs were performed on the HAR radar by the local service representative.

On each day of testing, the major operating parameters of the two radars were measured by representatives of the test team from the Applied Physics Laboratory/The Johns Hopkins University (APL/JHU) to assure that the radars were operating in a consistent manner each day. It was found from these measurements that the HAR radar was not operating within the original factory specification limits, particularly with respect to the radiated transmitter power. The transmitter peak power output is nominally 40,000 Watts; however, during the tests, the radiated power was found to be typically on the order of 15,000 to 20,000 Watts. The overall behavior of the HAR system indicated a general deterioration in the equipment, resulting in a generally unsatisfactory performance.

Maximum Range Detection

The following illustration presents plots of the experimentally measured target detection probability characteristics of the AIL and HAR radars. The curves indicate the measured probability of the radar detecting the target vessel (a U.S. Coast Guard 40-foot cutter) as a function of range. The maximum detection range is defined as the range at which the probability of detection (or blip-scan ratio) is 50 percent. The curves show that the maximum detection range of a 40-foot cutter by the HAR radar is approximately 5400 yards. For the AIL radar with circular polarization of the antennas, the maximum detection range for the 40-foot cutter is 27,000 yards (stern aspect) and 24,000 yards (bow aspect). The difference of 13 percent is attributed to the smaller echoing area of the bow aspect as compared with the stern aspect of the cutter. With linear polarization of the antennas, the AIL obtained a maximum detection range of 32,000 yards. It is apparent in the illustration that the maximum detection range of the AIL radar is far greater than that of the HAR radar for all modes of operation. A major cause of this performance disparity is believed to be the poor condition of the HAR radar system.



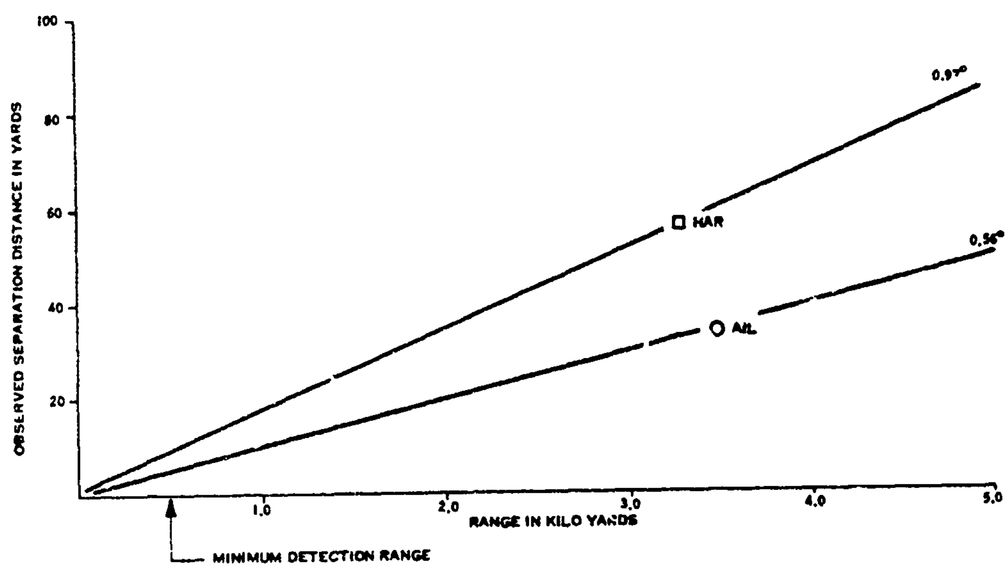
Maximum range detection comparison

Minimum Range Detection

It was found that the minimum detection range for both the AIL and the HAR radars was on the order of 500 to 600 yards. The minimum detection range was determined from observations of the disappearance of the target blip from the radar display while the vessels used in the test were returning to the Coast Guard station on YBI. The target blip always disappeared suddenly, and it is surmised that the target in each case had entered the radar shadowed zone of the island.

Angle Resolution

The angle resolution of the radars was determined experimentally by measuring the physical separation of the two 40-foot cutters at the time that two distinct target blips were first observed on the radar display while the cutters were separating from each other. The results of these tests are illustrated in the following figure. As indicated by the plots, the apparent angle resolution of the AIL radar is 0.56 degrees and 0.97 degrees for the HAR radar. It is pertinent to note that the measured data was taken at ranges of less than 5000 yards because of the poor range performance of the HAR radar.



Angle resolution comparison

Range Resolution

The range resolution of the AIL and HAR radars was measured in the same manner as that used for obtaining angle resolution. The results obtained are presented in the following table.

Range resolution test results for AIL and HAR radars.

Test	Range (Yards)	Resolution (Yards) AIL	Resolution (Yards) HAR	Mean Value (Yards) AIL	Mean Value (Yards) HAR	Comments
A	5040	70				AIL pulse width: 200 nanoseconds; HAR pulse width: 500 nanoseconds; range scale for both radars: 8.0 nmi
	5200		100			
	5360	50				
	5400	50	100			
	5600	45				
	5800	50				
				53	100	
B	3560		40			Pulse width for both radars: 50 nanoseconds; range scale for both radars: 4.0 nmi
	3720		42			
	3940		33			
	4420	30				
	4520	23				
	4700		53			
	8260	20				
	8620	22				
	8660	20				
	10,000	63				
	10,020	50				
				31	39.2	

When both radars were operated with short pulse (50 nanoseconds) transmission, the mean value of the observed range resolution of the HAR radar was 39 yards and 31 yards for the AIL radar. These values are much greater than the theoretical figure of 8.15 yards for the pulse length used. This discrepancy is reasonably assigned to pulse lengthening in the receiver and video amplifiers and an effective lengthening caused by a fixed minimum spot size on the cathode-ray tube display.

Wide pulse transmission results for both radars are also listed in the table. The AIL radar had an effective resolution of 53 yards, and the HAR radar has an effective resolution of 100 yards. Theoretical resolution for the AIL radar with wide pulse (200 nanoseconds) transmission is 32.6 yards, which is reasonably close to the experimental value. The HAR radar theoretical resolution with wide pulse (500 nanoseconds) transmission is 81.5 yards, which is also in close agreement with the experimental value.

Circular Polarization

The AIL radar can be operated with either linear or circular polarization of the antenna radiation; whereas, the HAR has only linear polarization. Theoretically and experimentally, it has been demonstrated that circular polarization tends to eliminate clutter or unwanted target return signals from rain drops. The circular polarization feature of the AIL radar was used in a number of tests when moderate to severe rain storms traversed the bay area. In all cases, the use of circular antenna polarization drastically reduced the clutter return on the display and enabled the detection of targets that had been completely obscured during linear polarization.

FTC and STC

A qualitative evaluation of the FTC and STC features of the two radars indicated no significant differences in the performance of these functions. It should be noted, however, that the poor range performance of the HAR radar tended to mask some of the performance advantages of the STC and FTC functions.

Conclusion

The AIL radar is superior to the HAR radar in all areas of performance and operational flexibility; however, the HAR radar is an older radar system with fewer built-in functions and was not operating within its rated performance envelope.

Recommendations

The AIL radar offers such a significant performance increase that consideration should be given to operator training and work studies to determine possible information filtering and analysis requirements

A side-by-side comparison should be conducted between the AIL radar and a modern off-shelf marine radar to determine more significantly the performance improvement obtainable by the AIL radar.

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SECTION 1

INTRODUCTION

1.1 GENERAL

The U. S. Coast Guard is currently engaged in a research and development program for vessel traffic systems. The Applied Physics Laboratory/The Johns Hopkins University (APL/JHU) is conducting an exhaustive test program to establish empirically the performance of the first experimental vessel traffic system. This system is presently being installed at San Francisco, California. The Comparison Test reported herein is the first in a series of tests that will be conducted during the total test program. The purpose of the Comparison Test was to perform a qualitative radar performance comparison between the existing Raytheon 1605 Harbor Advisory Radar (HAR) and the recently installed Airborne Instrument Laboratory (AIL) surveillance radar (AN/FPS-109(XN-1).

It should be noted that the HAR radar is an early-1960 type radar that uses vacuum tubes and related circuitry and display techniques. The HAR has been in continuous operational service with limited maintenance since its procurement by the Coast Guard. In contrast, the AIL radar design utilizes the latest solid-state integrated circuit technology with current state-of-the-art displ··s and antenna designs. The AIL radar was installed and operational for only a few months prior to the conduct of the Comparison Test and therefore has not been subjected to the effects of daily operational use such as has the HAR radar. A comparison test of the AIL radar with a similar contemporary design radar would probably have been more appropriate.

By performing a side-by-side comparison of the HAR and AIL radars, it was anticipated that common areas of desired performance, improvements in performance, and undesirable performance would be isolated, incorporated, or deleted as appropriate in future harbor surveillance radar system designs. The results of the Comparison Test,

coupled with the results derived from the next series of tests (which will be a thorough parametric and performance evaluation of the AIL radar), will produce a data base from which a universal harbor radar specification can be derived for the Coast Guard.

1.2 TEST APPROACH

Since the HAR and AIL radars, collocated at a site on Yerba Buena Island (YBI), operate at different frequencies in the X-band, detection and tracking of the same test target could be performed simultaneously by the two radars. This procedure of tracking test targets simultaneously under the same sea state and other atmospheric conditions reduced the number of variables pertinent to the test and allowed a direct, relative comparison to be made. Therefore, the primary data derived from the test is a relative performance comparison of the HAR and AIL radars, rather than the absolute performance of either radar.

The results of the Comparison Test are presented as comparative data and include the following comparisons for the AIL and the HAR radars:

a. Maximum detection range
b. Minimum detection range
c. Angle resolution
d. Range resolution
e. Fast Time Constant (FTC) on/off
f. Sensitivity Time Control (STC) on/off
g. Shadowed areas
h. Blip (size) characteristics

1.3 REPORT ORGANIZATION

The AIL and the HAR radars evaluated in the Comparison Test are briefly described in Section 2. This section also presents illustrations of the types of test targets used in the test. The manner in which the test was conducted and a summary of the events are presented in Section 3. Section 4 presents the test results and related discussion, and the major conclusions that can be drawn from these results are presented in Section 5. The procedures used in ascertaining the daily operating parameters of the radars and the values obtained are given in Appendix A.

SECTION 2

DESCRIPTION OF MATERIEL

2.1 GENERAL

This section presents descriptions of the AIL and HAR radars that were evaluated during the Comparison Test. In addition, the targets that were used during the test are illustrated and briefly described.

2.2 HAR RADAR

The HAR radar (Figure 2-1) is the Raytheon Mariners Pathfinder Model 1605 and is a successor to the 1400 series of Mariner Pathfinder radars. The HAR radar, which operates in the X-band, is composed of an indicator, a modulator-transmitter receiver unit, and an antenna unit.

The indicator is of the console type and drip-proof. A 16-inch aluminized glass type cathode-ray tube (CRT) provides a large scale presentation. There are seven range scales: 0.5, 1, 2, 4, 8, 20, and 50 nautical miles (nmi). The ratio of adjacent scales is approximately 2:1, permitting a choice of areas to be scanned. The minimum range is 50 feet. Fixed range markers or range rings are provided on all scales. A movable range mark, adjustable by a calibrated range crank with illuminated counter, permits ranging to any point 0.25 to 20 miles. Surrounding the indicator screen are two concentric azimuth dials calibrated in 1-degree divisions. The inner dial is fixed; the outer dial may be hand-rotated by a crank. A cross-line bearing cursor intersects both azimuth scales and may be manually rotated in either direction to permit alignment with an object for determining bearing.

A detachable viewing hood shields the screen from excessive external light and reduces reflections. A flexible eyepiece, which attaches to the hood, is provided for viewing under conditions of ambient light. The most frequently used controls are located on the

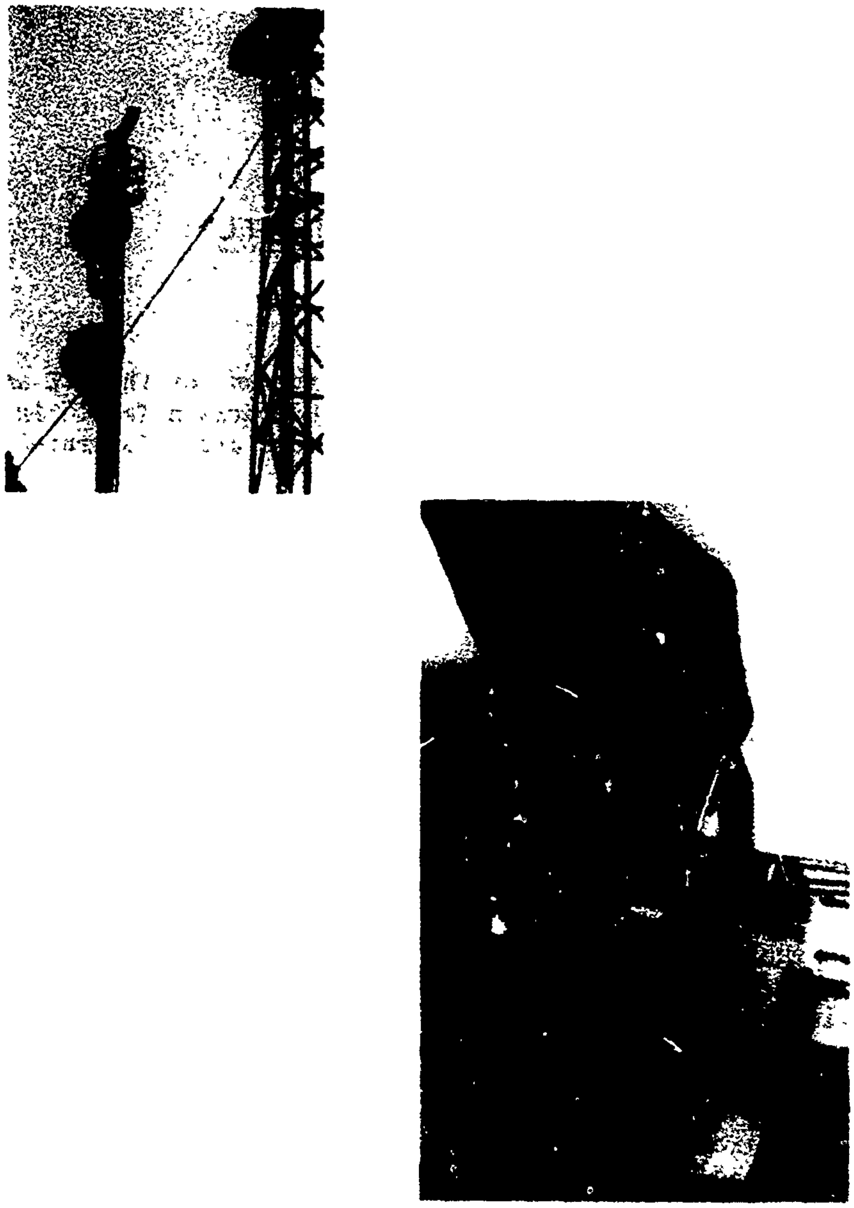

FIGURE 2-1. HAR radar antenna and PPI display.

sloping front panel and on the vertical panel directly below. Little used controls are contained under two hinged covers directly beneath the vertical panel. Tune and magnetron current readings, as well as input line voltage and dc voltage readings are shown on a meter located on the right side covered control panel. A Range switch is located on the horizontal panel, between the two hinged covers. An STC-Gain control on the vertical panel permits adjustment of receiver sensitivity and sea return suppression.

The modulator-transmitter receiver unit is contained in a drip-proof case. The assemblies included in this unit are the transmitter, the preamplifier, and the power supply circuits. Space is also provided for the waveguide ferrite insulator. Pulse power for the transmitter is produced by a hard tube modulator. A 0.05-microsecond pulse is used for the 0.5-, 1-, 2-, and 4-nmi ranges to provide range discrimination; a 0.5-microsecond pulse is used on the 8-, 20-, and 50-nmi ranges for range detection. A magnetron type oscillator tube converts the pulse power into microwave energy for transmission. Radio energy is conducted to and from the sharp-beamwidth antenna by means of a waveguide. A duplexer is used for switching the antenna from the transmitter to the receiver and vice versa.

The preamplifier consists of a cascode amplifier and two amplifiers. The ferrite insulator between the magnetron and the duplexer eliminates unwanted long-line effects due to very long waveguide runs between the antenna and the modulator-transmitter receiver unit.

The antenna consists of a pedestal on which is mounted the slotted array assembly. This assembly contains the motor mechanism for rotating the array assembly, which is a slotted waveguide radiating a very sharp beam.

The major parameters of the HAR radar are listed in Table 2-1.

2.3 AIL RADAR

The AIL radar system (Figure 2-2) consists of two high resolution, dual-channel radars that monitor the entire harbor area from a single operations center. One radar is installed overlooking a seaward approach to the harbor, while the second is installed at the operations center. The remote radar provides video, bearing,

TABLE 2-1. Parameters of HAR and AIL Radars.

Parameter	HAR Radar	AIL Radar
Peak Power (kilowatts)	40 nominal	50 nominal
Frequency (band)	X (Marine)	X (9.3 to 9.5 GHz)
Beamwidth (degrees)	0.60	0.30
Pulse Width		
Short (nanoseconds)	50	50
Long (microseconds)	0.5	0.2
Scales (miles)	0.5, 1, 2, 4, 8, 20, and 50	2, 4, 6, 8, 16, and 32
Fast Time Constant	Yes	Yes
Sensitivity Time Control	Yes	Yes
Intermediate Frequency Bandwidth (megahertz)	30 (narrow pulse); 8 (wide pulse)	22 (narrow pulse); 10 (wide pulse)
Pulse Repetition Frequency (pulses per second)	1000 and 4000	1000, 2500, and 4000
Antenna Scan Rate (revolutions per minute)	20	20.6
Polarization	Horizontal	Vertical or circular (PTB); horizontal or circular (YBI)
PPI	16-inch (operator); P7 phosphor	16-inch (operator); 12-inch (maintenance); P7 phosphor

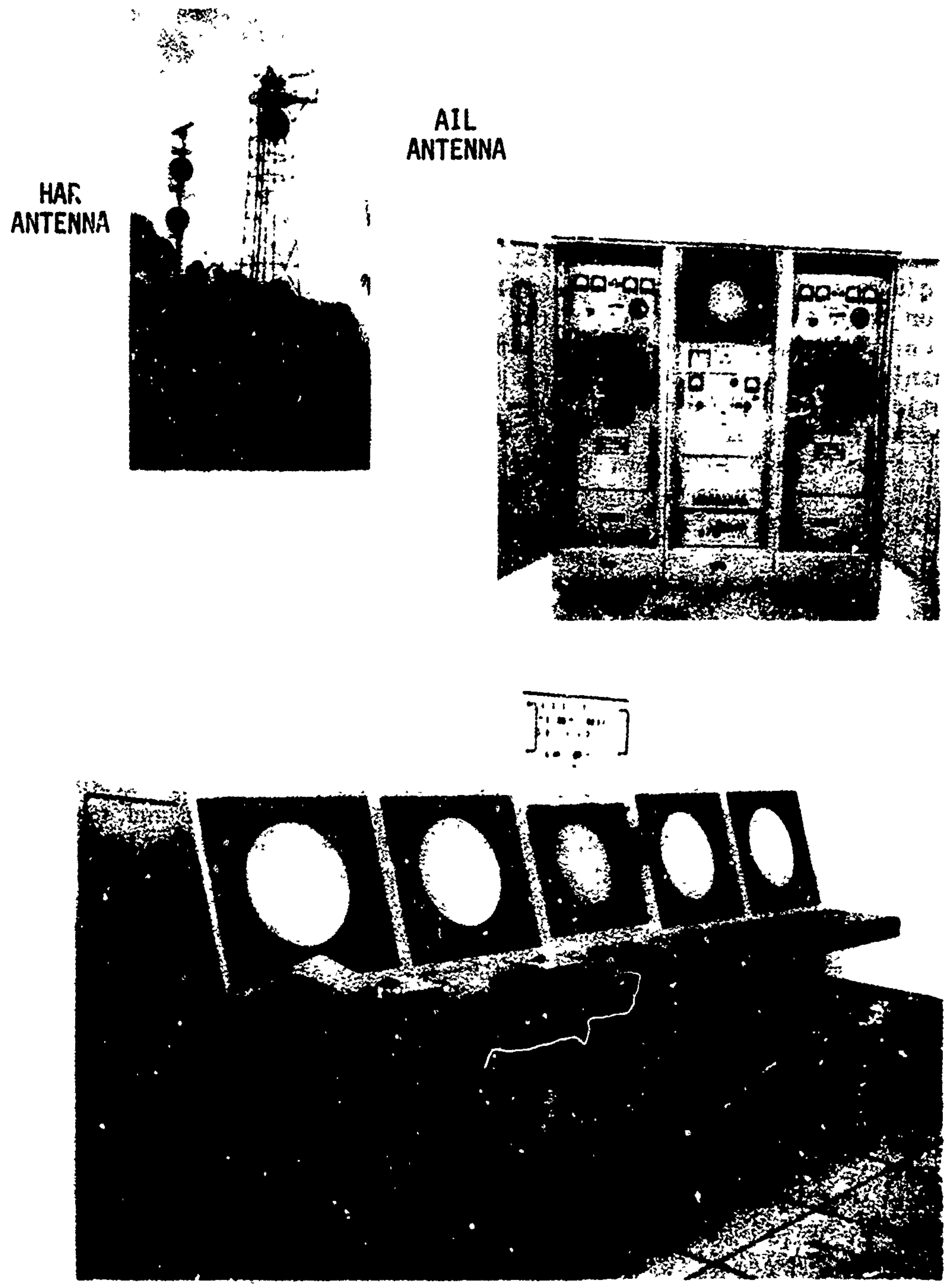

FIGURE 2-2. AIL radar antenna, equipment consoles, and PPI display.

and trigger information via a wideband video data link, while control and monitoring is via a ultra-high frequency (UHF) data link or a telephone line.

The AIL radar is designed to detect and display both large ships and the numerous small boats and buoys in the harbor and its approaches under heavy sea and rain clutter conditions. In rain and sea clutter, performance is accomplished by matching antenna polarization to the expected sea clutter conditions (i.e., vertical polarization for seaward side and horizontal for harbor conditions) and combining this with the use of a fast time constant (FTC) and logarithmic receiver processing. Rain clutter is further minimized by selectable circular polarization. The normalization of radar returns from within 1375 feet of the radar to maximum range is accomplished by the use of antenna pattern shaping using dual feeds and sensitivity time control (STC) techniques.

A central control and monitoring center is located at the display consoles. These consoles are capable of five radius offset presentations of radar video with electronic leading line and cursors. These devices permit measurement of relative position of vessels with respect to the other vessels, buoys, or channel center lines.

Operational considerations required radar coverage of all significant channel areas, both within and approaching the harbor area. The siting considerations therefore determined the number and type of radars necessary to provide harbor surveillance. In the San Francisco area, the two sites selected were Point Bonita (PTB) to cover the seaward approach and Yerba Buena Island (YBI) to cover the harbor itself. The radar antenna at the PTB site is on a 60-foot tower, 330 feet above sea level. The radar antenna at the YBI site is on a 90-foot tower, 415 feet above sea level. These high elevations provide a commanding view of both the harbor and its seaward approaches.

The antenna group at each radar site is composed of a high resolution antenna mounted on a pedestal, which provides continuous rotation at 20 revolutions per minute and 14-bit shaft encoder readout of instantaneous bearing angle. The antenna is a parabolic cylinder reflector with a pillbox feed, which normally is linearly polarized, but can be switched to a circular polarization to cope with heavy precipitation.

The transmitter uses a long-life magnetron conservatively rated at 50 kilowatts (kW) peak. Two pulse lengths, 50 and 200 nanoseconds, are available, selected by switching in the appropriate pulse

forming network. The synchronizer provides timing for the various radar functions and allows selection of a 1000, 2500, or 4000 pulses per second repetition rate. Choice of pulse length and pulse repetition frequency (prf) permit tradeoffs in resolution and range to be made by the operator, depending on the traffic problem at the moment.

The log receiver provides a dynamic range of over 80 decibels (dB) to cover the wide range of target size, clutter conditions, and precipitation losses. As the pulse length is changed, a filter having a bandwidth appropriate to the pulse length is automatically selected.

For transmission to the display site, the radar video, triggers, and bearing data are converted to a time-shared serial form in the composite generator. Transmission of this composite video from the remote PTB site to the YBI center is by microwave link. At YBI, the radar transceiver is housed in a room near the room containing the display console so that the composite video transmission is over a coaxial line. This serial format of the composite video is also convenient for recording on video tape recorders for permanent records of traffic movements and incidents.

A separator in the recovery group at the YBI remote cabinet at the display site converts the composite video back to parallel form in which the video pretrigger, trigger, and 14-bit parallel bearing code are on separate lines for driving the operational displays to provide live real-time data. The live data enables the operator to advise ships of other traffic and potential hazards. The tape recorded data can be used for experimental purposes, analysis, and evaluation of the system, for training personnel, and as a record in the event of an accident.

Any operational display can be switched to show data from either radar site. Range scales of 2, 4, 8, 16, and 32 nmi are selectable and the display may be off-centered by up to five radii. These controls permit the operator to set up the displays in the most effective combination to show, for example, the seaward approach to the Golden Gate and the inner harbor with critical areas expanded for closer examination. Range rings are provided at one-half, three-quarters, and full range.

Six lead lines can be set up on each display independently at installation to mark traffic lanes or boundaries of interest. A cursor permits the operator to measure the angle and distance between

any two objects on the display and read the angle and distance on numerical readouts.

Maintenance PPI displays at each radar site and associated remote monitor/control panels are provided for maintenance of the radars. The remote group provides the means of monitoring and controlling the unattended equipment by personnel at the display site. These functions are controlled by wire lines between the display site and the YBI radar site and by simple telemetry between the display site and the PTB site 8 miles away. The monitoring and control functions for the two radar sites are handled in the same manner, with identical controls and indicators on the monitor/control panel.

Remoting of the monitor and control functions for PTB is accomplished by using sequential scanning encoders and decoders. The encoders are parallel-to-serial converters, which continuously scan the on/off inputs and convert these to a serial pulse train for transmission via the UHF data link. The decoders are serial-to-parallel converters, which receive and sort the serial information, in sequence, and store it in parallel outputs that are available to drive the control relays or indicator lamps. Transmission in the opposite direction uses the same technique in reverse. The data can also be transmitted over telephone lines.

The major characteristics of the AIL radar are also given in Table 2-1.

2.4 TARGETS

The targets used during the test included a 40-foot cutter (Figure 2-3), a 56-foot wooden hull tug boat (Figure 2-4), and a 210-foot cutter (Figure 2-5).

FIGURE 2-3. 40-foot cutter used as test target.

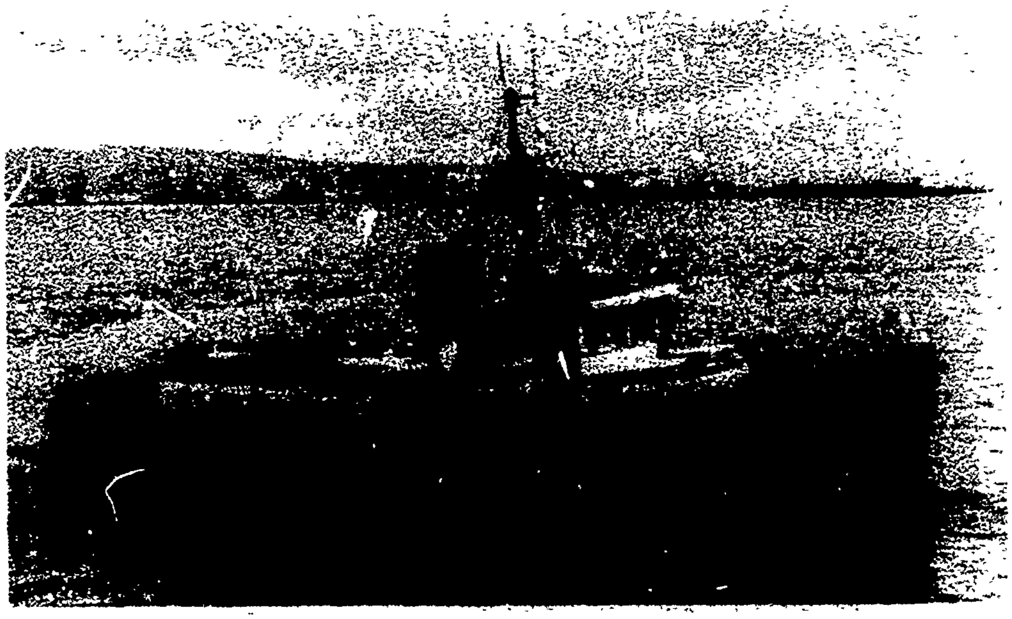

FIGURE 2-4. 56-foot tug boat used as test target.

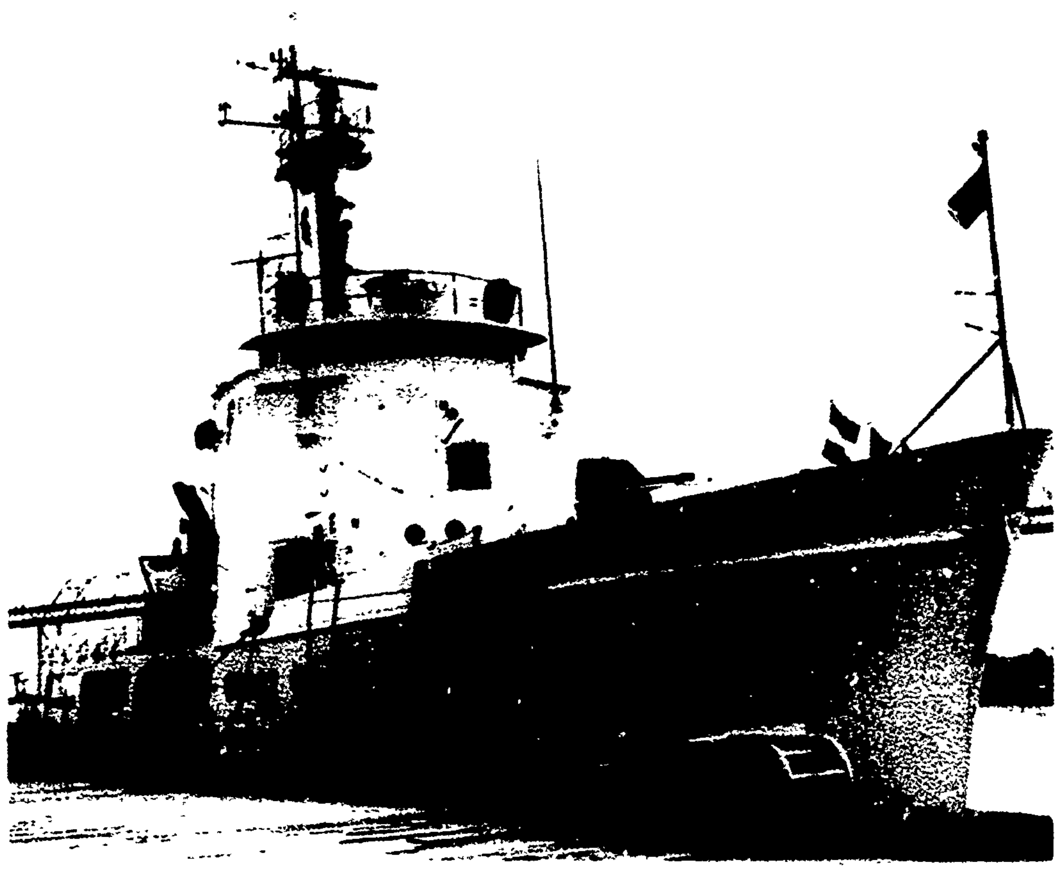

FIGURE 2-5. 210-foot cutter used as test target.

SECTION 3

CONDUCT OF THE TEST

3.1 GENERAL

The tests that were made in support of the Comparison Test were conducted from 6 February through 16 February 1973 in the San Francisco/Oakland Harbor area. These tests were made in accordance with the HAR/AIL Comparison Test Plan, reference (a). In preparation for these tests, and on a daily basis, the parameters of each radar were measured and recorded. Target services for testing were provided by the San Francisco U.S. Coast Guard, stationed at YBI. In general, one or two 40-foot metal hull cutters were provided in addition to a 56-foot wooden hull tug boat. The following paragraphs present brief descriptions of the individual tests that were conducted.

3.2 TEST I, NORMAL RADAR MODES/CLEAR ENVIRONMENT

3.2.1 Test I-1, Range Detection

3.2.1.1 Maximum Range. The 40-foot cutter and the 56-foot tug boat were vectored on radial courses from YBI, and blip-scan ratio measurements were made for the HAR and the AIL radars. Data were collected for each radar until the blip-scan ratio fell below a value of 50 percent, which indicated the maximum detection range for each radar.

3.2.1.2 Minimum Range. The 40-foot cutter, moving on radial courses to YBI, was tracked by both the HAR and the AIL radars until the target disappeared from the plan position indicator (PPI). This data was recorded and constituted the minimum range detection for each radar.

3.2.2 Test I-2, Angle and Range Resolution

3.2.2.1 Angle Resolution. Two 40-foot cutters were vectored on a radial course at ranges between 2000 and 5000 yards from YBI. Upon command from YBI, the cutters separated and followed opposite courses

that were 90 degrees to the YBI radars. When two distinct targets appeared on both the HAR and the AIL PPI displays, a mark was given to the cutter crews to measure the distance of separation. This distance and the range were recorded for each radar.

3.2.2.2 Range Resolution. Two 40-foot cutters were vectored on a radial course at ranges between 2000 and 5000 yards. Upon command from YBI, the cutters separated: one cutter following a course towards YBI, the other cutter following a course in the opposite direction. When two distinct targets appeared on both the HAR and AIL radars, a mark was given to the cutter crews to measure this distance of separation. This distance and the range were recorded for each radar.

3.2.3 Test I-3, Target Blip (Size) Characteristics

Three cutters (40, 82, and 210 feet) were vectored in a line and on a course that presented a beam aspect to both the HAR and AIL radars. PPI photographs were made and the blip (size) measured for each cutter on each radar display. The range scales of the PPIs were varied, and the process was repeated.

3.3 TEST II, DYNAMIC TARGETS

3.3.1 Test II-1, Pier and Target Resolution

The 56-foot wooden tug boat made simulated departures from Pier 27 in the San Francisco harbor. Both the AIL and the HAR radars tracked the tug and the pier. When both the tug and the pier appeared as distinct targets on the PPI display, a mark was given to the tug crew and the distance from the tug to the pier was measured. This data was collected and recorded for each radar.

3.3.2 Test II-2, Alameda Estuary and Passing Targets

While traversing the Alameda Estuary, the 56-foot wooden tug passed other targets of opportunity in the channel. Data was recorded on both the HAR and AIL radar capability to define the passing of the two targets or the merging of the two targets into one.

3.4 TEST III, WEATHER TESTS

3.4.1 Test III-1, Sea Clutter Suppression With Antenna Polarization

While the 40-foot cutter was vectored in an area of heavy chop (sea state of approximately 3), both the HAR and the AIL radars tracked the target. Blip-scan measurements and PPI photographs were made to record the data for each radar. The polarization of the AIL radar was then changed to circular, and the process was repeated. The performance of the circular polarization of the AIL radar was compared with the linear polarization of the AIL and the HAR radars.

3.4.2 Test III-2, Rain Suppression With Antenna Polarization

The 40-foot cutter was vectored in a rain area, and the circular polarization of the AIL radar was compared with the linear polarization of the AIL and the HAR radars.

3.4.3 Test III-3, Clutter and Rain Suppression With STC and FTC Modes

The 40-foot cutter was vectored in a rain area, and the tracking performance of both the AIL and the HAR radars was measured with and without the use of FTC and STC. Data were also collected for the AIL radar to measure the performance of the radar using circular polarization with and without FTC.

3.5 TEST IV, PPI STABILITY

Even though no specific tests were conducted to determine PPI stability, operators' observations during the test were documented to indicate areas of instability. It should be noted that corrections were made to these areas during the test period.

3.6 TEST V, SHADOWED AREAS

3.6.1 YBI Shadowed Area

During the Comparison Test, it was noted that a dead zone appeared on each radar. By the physical location on YBI, portions of the island mask the radar beams. A 40-foot cutter was vectored through this masked area, and the dead zone for both radars was plotted.

3.6.2 Alcatraz Island Shadowed Area

A 40-foot cutter was vectored to an area in the vicinity of Alcatraz Island. Both the AIL and the HAR radars tracked the target until it disappeared on the PPI displays (as it passed on the western side of the island). Many tracks were recorded, and the complete shadowed zone was plotted for each radar.

3.7 TEST EVENT MATRIX

Table 3-1 presents a summary of all the data events that occurred during the Comparison Test. Lmphasis was placed on Test I series where 55.9 percent of all the data were collected. Test II series represented 15.5 percent; Test III, 16.5 percent; and Test V, 11.9 percent.

TABLE 3-1. Summary of events conducted for Comparison Test.

Test Series	Events	Total
I-1, Maximum/Minimum Range	25	
I-2, Angle/Range Resolution	80	
I-3, Target Blip (Size) Characteristics	3	
		108
II-1, Pier/Target Resolution	26	
II-2, Alameda Estuary/Passing Targets	4	
		30
III-1, Sea Clutter/Polarization	14	
III-2, Rain Suppression/Polarization	3	
III-3, Clutter Suppression/FTC	15	
		32
V, Shadowed Areas		
Alcatraz Island	7	
YBI Dead Zone	16	
		23
Comparison Test - Total Events		193

SECTION 4

RESULTS OF THE TEST

4.1 GENERAL

This section presents the results of the tests performed during the comparison of the HAR and AIL radars located in the San Francisco Harbor area.

4.2 DAILY CHECK OF RADAR PARAMETERS

The operating parameters of the AIL and HAR radars were measured on each day of the test with only one exception: on 8 February, the test equipment was not available to measure the peak power output of the HAR radar. Measurements of the radar parameters were made to assure that the equipments were operating in a uniform manner throughout the test period. A detailed listing of the parameters measured and the values obtained are given in Appendix A.

4.2.1 HAR Radar

During the first series of parametric measurements, the HAR radar transmitter power output was approximately 4.7 decibels (dB) below the specified value of 40 kilowatts (kW) on the 4.0-nmi range scale with narrow pulse and 7.4 dB below 40 kW on the 8.0-nmi range scale with wide pulse. For the total test period, the power output was on the average 3.8 dB below the specified power on the 4.0-nmi range scale and 6.9 dB below the specified power on the 8.0-nmi range scale.

The average minimum discernible signal (MDS) of the HAR receiver was -93.4 dBm (decibels reference to 1 milliwatt), which was approximately +1.6 dB higher than the specified -95 dBm.

It should be noted that on the last day of testing, the HAR transmitter power was 0.8 dB higher than the specified power and the MDS was -95 dBm, which was the value specified. This unexpected radar

performance was correlatable only with the fact that the weather was clear and dry.

4.2.2 AIL Radar

The mean power output of the AIL transmitter during the test was at or above the specified power output level for four conditions of operation (i.e., 200 nanosecond pulse at 1000, 2500, and 4000 prf and 50-nanosecond pulse at 1000 prf). The mean power output was 1.4 dB down from the specified power with the 50-nanosecond pulse at 4000 prf and 1.2 dB down with the 50-nanosecond pulse at the 2500 prf. A maximum variation from the mean power output of -2 dB was observed on one occasion; however, the typical variation was less than ±1.0 dB.

The MDS of the AIL receiver had a mean value of -93.9 dBm with a maximum deviation of -2.1 dB.

4.3 TEST I, NORMAL RADAR MODES/CLEAR ENVIRONMENT

4.3.1 Test I-1, Range Detection

4.3.1.1 Maximum Range. A series of tests to determine the maximum detection range capabilities of the HAR and the AIL radars tracking 40-foot cutters was conducted in weather conditions ranging from clear to heavy rain. As a result of the tests and the known and measured radar parameters, the approximate equivalent echoing cross section of the cutter for the stern aspect was 4.0 square meters with an estimated error of ±2.0 square meters. The maximum detection range for the tests was defined as the range at which the blip-scan ratio reached a value of 50 percent. The blip-scan was measured by counting the number of times that the target echo was displayed on the PPI during a 1-minute period and dividing by the number of antenna scans that occurred in a 1-minute period (i.e., 21). For a unity blip-scan ratio, the target echo is displayed on each scan.

The results of the maximum detection range tests are shown in Figures 4-1 through 4-6. Figure 4-1 illustrates the results of the maximum detection range tests for the HAR radar tracking the 40-foot cutter in clear weather with calm seas. The maximum detection range for the radar tracking the stern aspect was approximately 5400 yards and nearly the same for the radar tracking the bow aspect. (The data collected during the test was not sufficient to define clearly the maximum detection range of the radar for the bow aspect.)

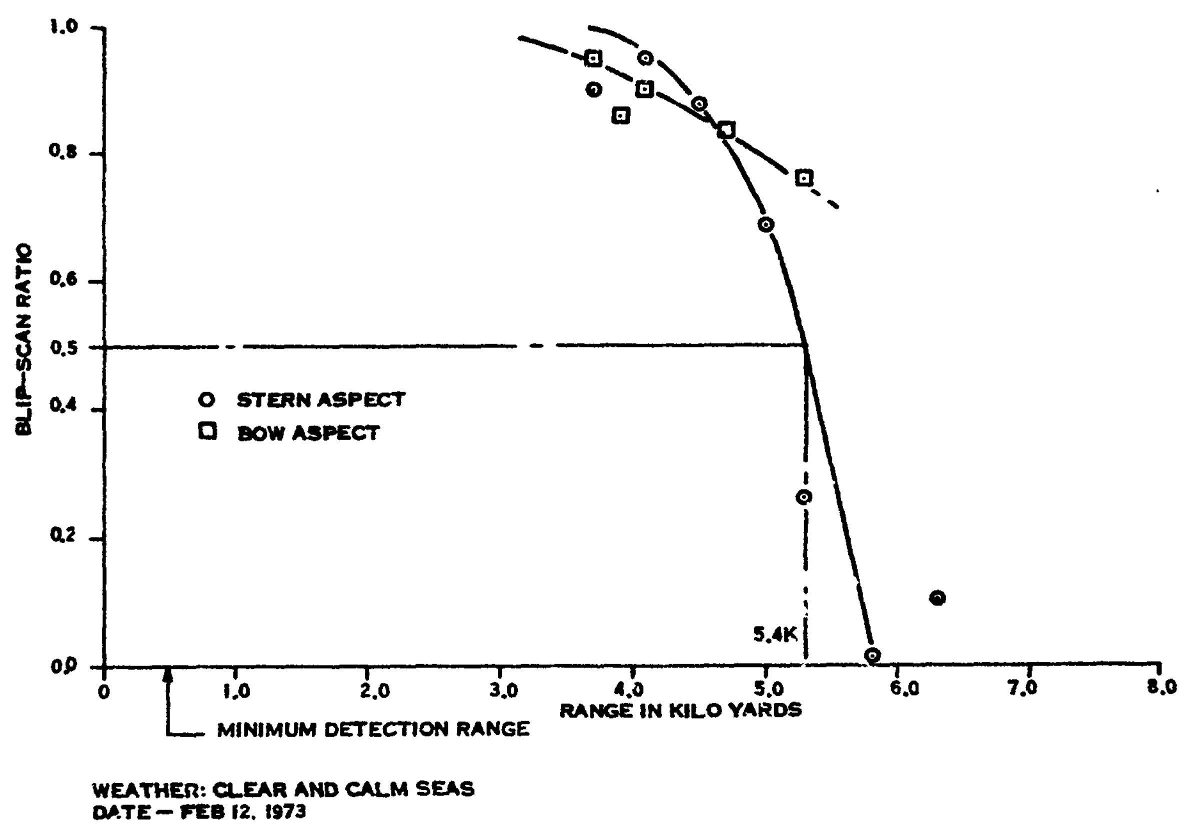

FIGURE 4-1. HAR radar tracking 40-foot cuiter.

Figure 4-2 shows the results of the tests for the AIL radar with linear and circular antenna polarization on a relatively good weather day. The maximum detection range for the radar with circular polarization tracking the stern aspect of the 40-foot cutter was approximately 24,000 yards when the radar tracked the bow aspect of the cutter. This difference was attributed to an apparent difference of equivalent echoing cross section for the bow and stern aspects. The maximum detection range of the radar with linear polarization tracking the stern aspect of the cutter was 32,000 yards, which was considerably more than the 27,000 yards obtained for the radar with circular polarization. This larger range obtained with linear polarization was attributed to the tendency of the target echo return to be depolarized because of the irregular structure of the target. Therefore, there was normally some reduction in maximum detection range when the radar was switched from linear to circular polarization.

The reduction in maximum detection range with the use of circular polarization, however, should be compared with the improved detection performance obtained with circular polarization in rain. The use of the circular polarization almost eliminated the return from the rainfall, thus reducing the apparent clutter on the PPI presentation. Following Figure 4-7 and 4-8, which introduce the orientation of the scope displays, are photographs of typical rainfall clutter observed with and without the use of circular polarization. Figure 4-9 shows the AIL PPI display with linear antenna polarization and Figure 4-10 shows the same display a few minutes later with circular antenna polarization. The improvement in detection capability is readily obvious by a comparison of these two photographs.

Figure 4-1 and 4-2 are combined in Figure 4-3 to present a comparison of the AIL and HAR radars for maximum detection range. This figure illustrates the greater range capability of the AIL radar as compared with the HAR radar. The very poor performance of the HAR radar was attributed to the reduction in power output of the HAR transmitter as previously discussed. Because of the poor performance of the HAR radar, additional maximum range detection tests were conducted with the HAR radar tracking larger target vessels.

Figure 4-4 illustrates the results of the HAR tracking tests conducted while the radar tracked a 56-foot tug and an 82-foot cutter. In all cases, the weather was moderately good to fair. Curve (A) of Figure 4-4 indicates a maximum detection range of 6000

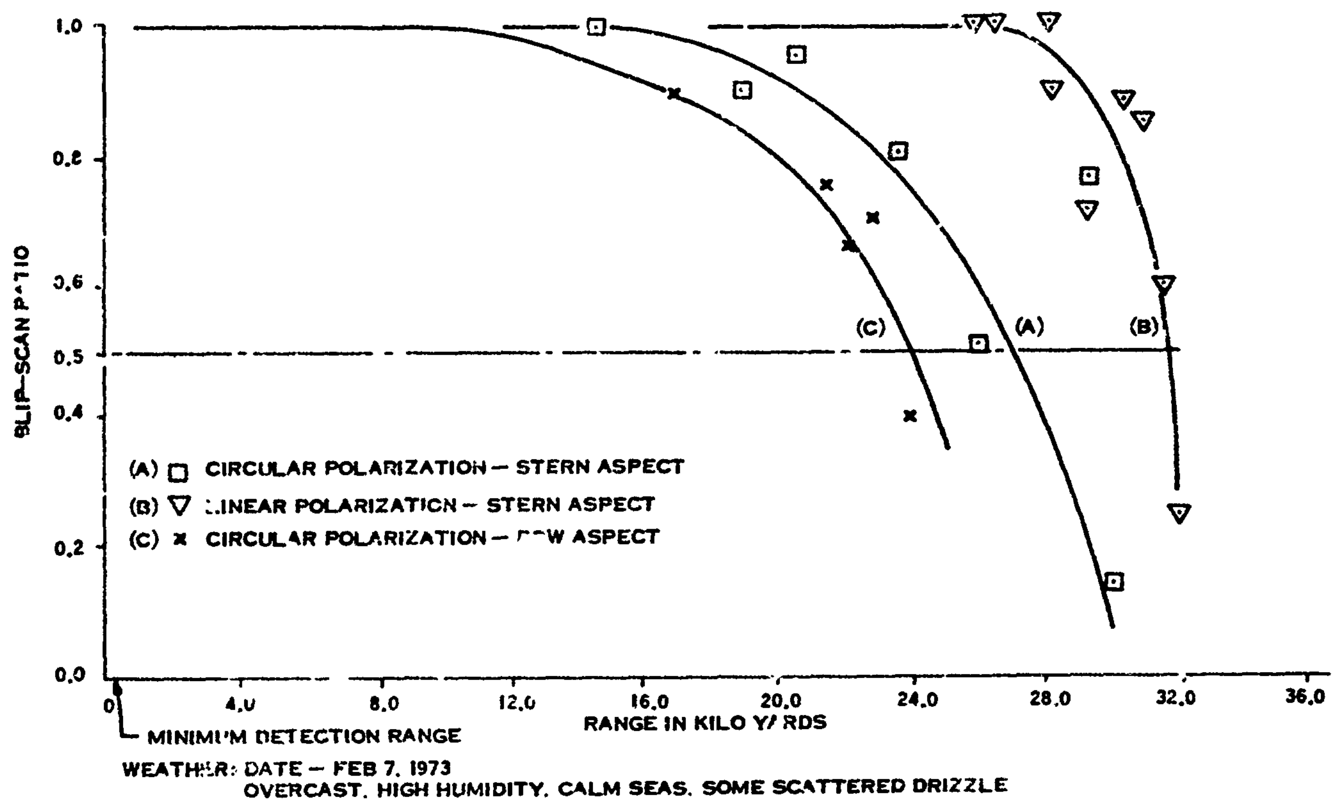

FIGURE 4-2. AIL radar (circular and linear) tracking 40-foot cutter.

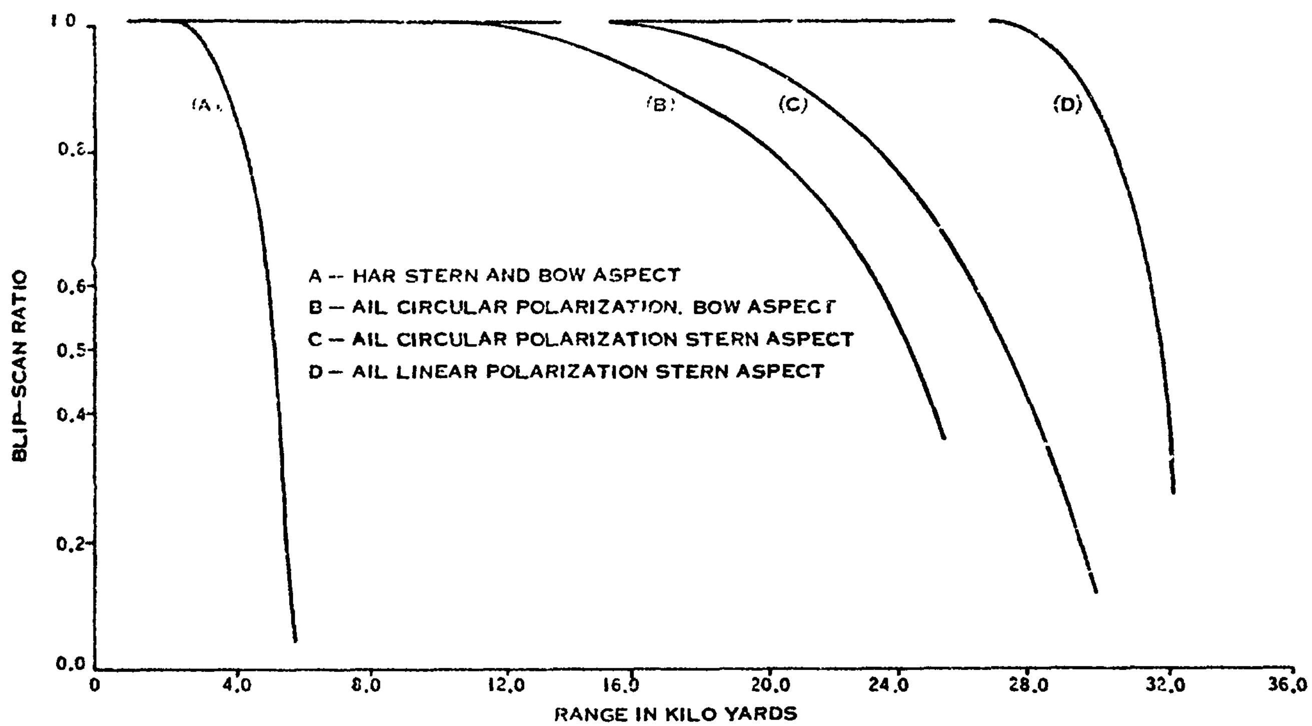

FIGURE 4-3. Comparison of HAR and AIL maximum detection ranges.

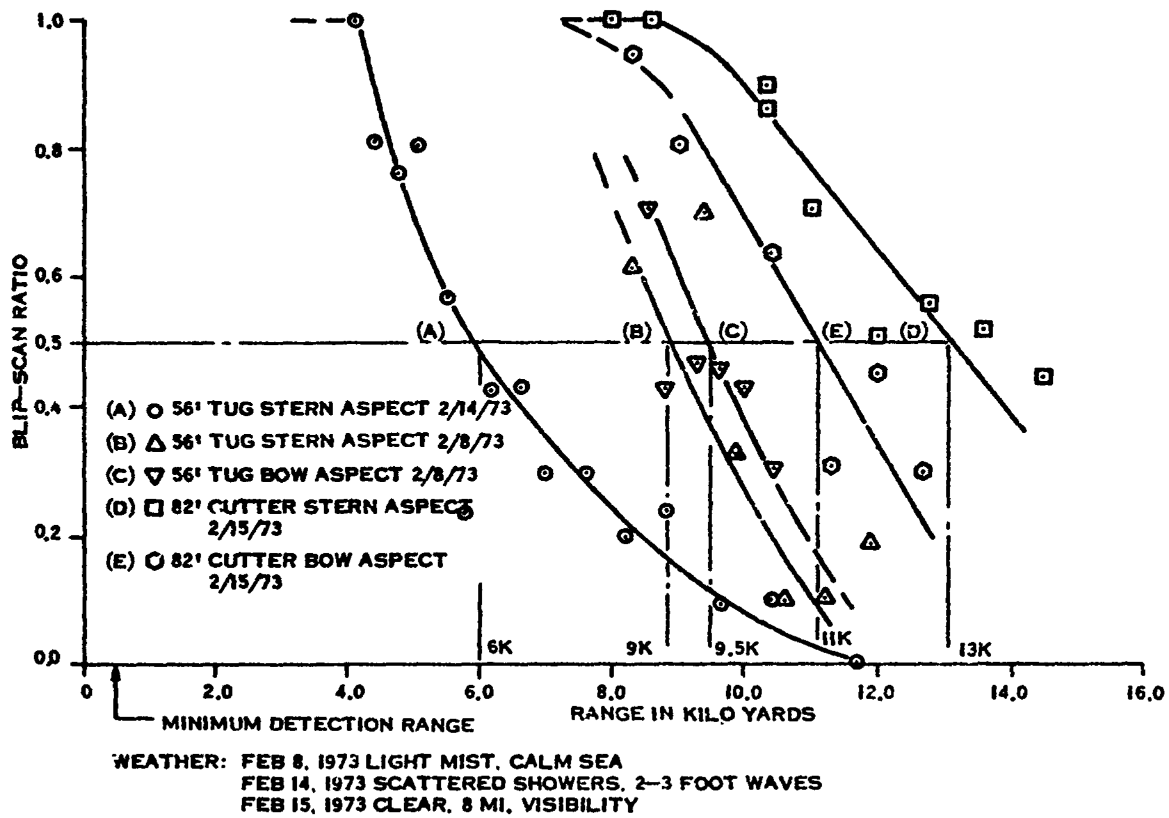

FIGURE 4-4. HAR radar tracking 56-foot tug and 82-foot cutter.

yards for the HAR radar tracking a 56-foot tug on the stern aspect. During this test, there were some scattered showers in the area and 2- to 3-foot seas. Curves (B) and (C) show the results obtained when the HAR tracked the 56-foot tug on a calm day with some light mist. For stern aspect tracking, the maximum detection range was approximately 9000 yards. For the bow aspect, the maximum detection range was approximately 9500 yards, which was an insignificant difference in range. Curves (D) and (E) show the results of the tests of the HAR radar tracking the 82-foot cutter on a clear day. The maximum detection range of the radar tracking the stern aspect was approximately 13,000 yards and approximately 11,000 yards for the bow aspect. (In all cases, it was found that the blip-scan ratio for the AIL radar remained at unity for the total duration of the HAR tests.)

It was apparent that the maximum detection range of the HAR radar increased almost in proportion to the size of the vessel being tracked; however, the HAR maximum detection range did not equal that of the AIL radar while the 40-foot cutter was being tracked.

The results of an abbreviated maximum detection range test of the AIL radar tracking a 40-foot cutter are shown in Figure 4-5. This test was terminated at the request of the crew aboard the cutter because of very high seas. During the test, there was very heavy rainfall and for a very short period, a hail storm. The curves in Figure 4-5 illustrate that the blip-scan ratio dropped to 0.85 with circular polarization at a range of 9000 yards and to 0.80 with linear polarization at a range of 16,100 yards while the radar was tracking the stern aspect of the cutter.

The corresponding tracking data for the HAR radar is shown in Curves (A) and (B) of Figure 4-6. Curve (A) is incomplete because of the termination of the test; however, this curve indicates that a blip-scan ratio of approximately 0.80 was obtained at a range of 3000 yards. During the initial outbound event, the maximum detection range was reached at approximately 3500 yards. A comparison of the data presented in Figure 4-5 and 4-6 indicates the better detection capability of the AIL radar as compared with the HAR radar in heavy weather conditions. Curves (C) and (D) show the maximum detection range test results for the HAR radar tracking a 40-foot cutter inbound and outbound in light rain and calm seas. The stern aspect data shown in Curve (D) indicates a maximum detection range of

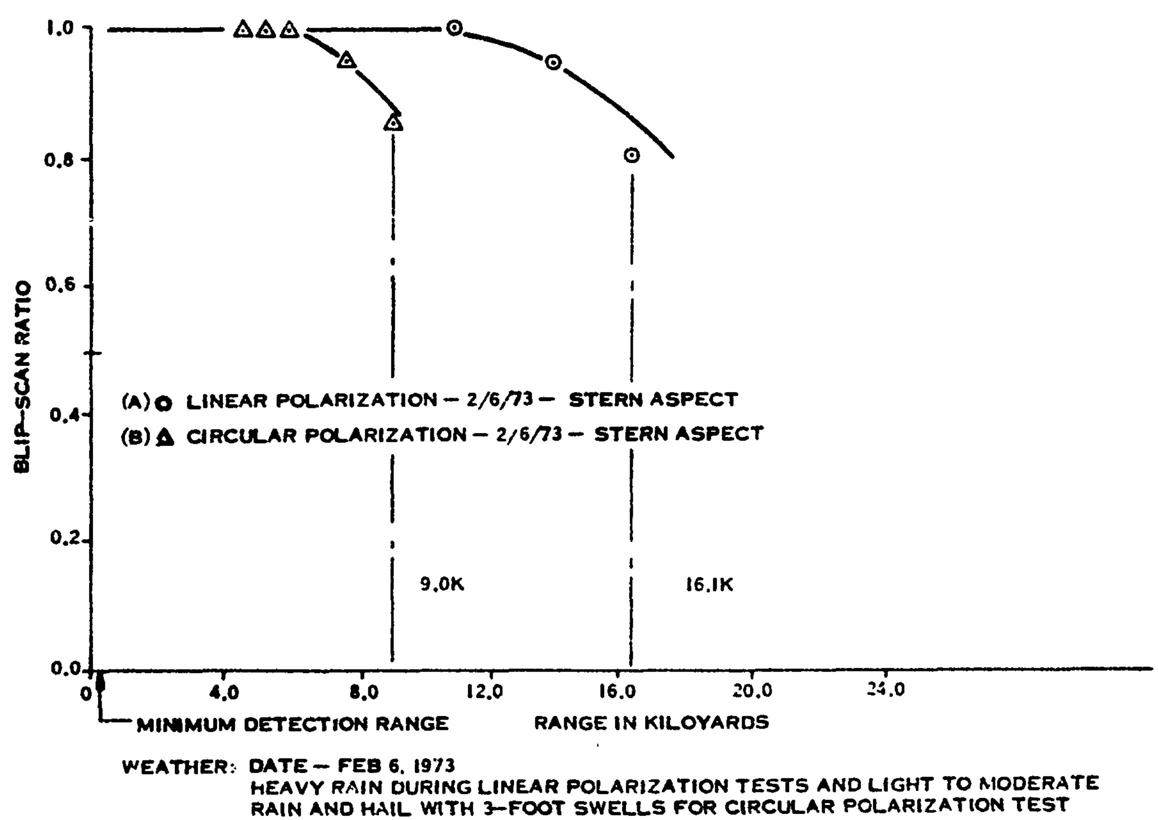

FIGURE 4-5. AIL radar (linear versus circular polarization) tracking 40-foot cutter during heavy rain.

5000 yards. Curve (C), which presents the data for the inbound event (bow aspect), indicates a somewhat greater range of 6300 yards; however, this data is somewhat suspect because of the random scattering of the data points.

4.3.1.2 Minimum Range. The minimum detection range for both the AIL and the HAR radars was observed to be approximately 500 to 600 yards. In all cases the target return was observed to disappear suddenly as the cutter approached the island. Therefore, it was most likely that the target passed into the radar shadow zone of YBI rather than reaching the true minimum range boundary of the radar.

PPI Display Orientation

Figure 4-7 is a greatly reduced reproduction of a San Francisco Harbor chart. The chart includes depth soundings, restricted areas, compass rose, as well as call outs of significant landmarks. This chart is supplied to provide general orientation of the locations referenced in this report. Figure 4-8 shows both the chart and a radar display centered at the 3 nautical mile range. The call outs on the radar display are intended to help those readers not familiar with PPI scope display interpretation.

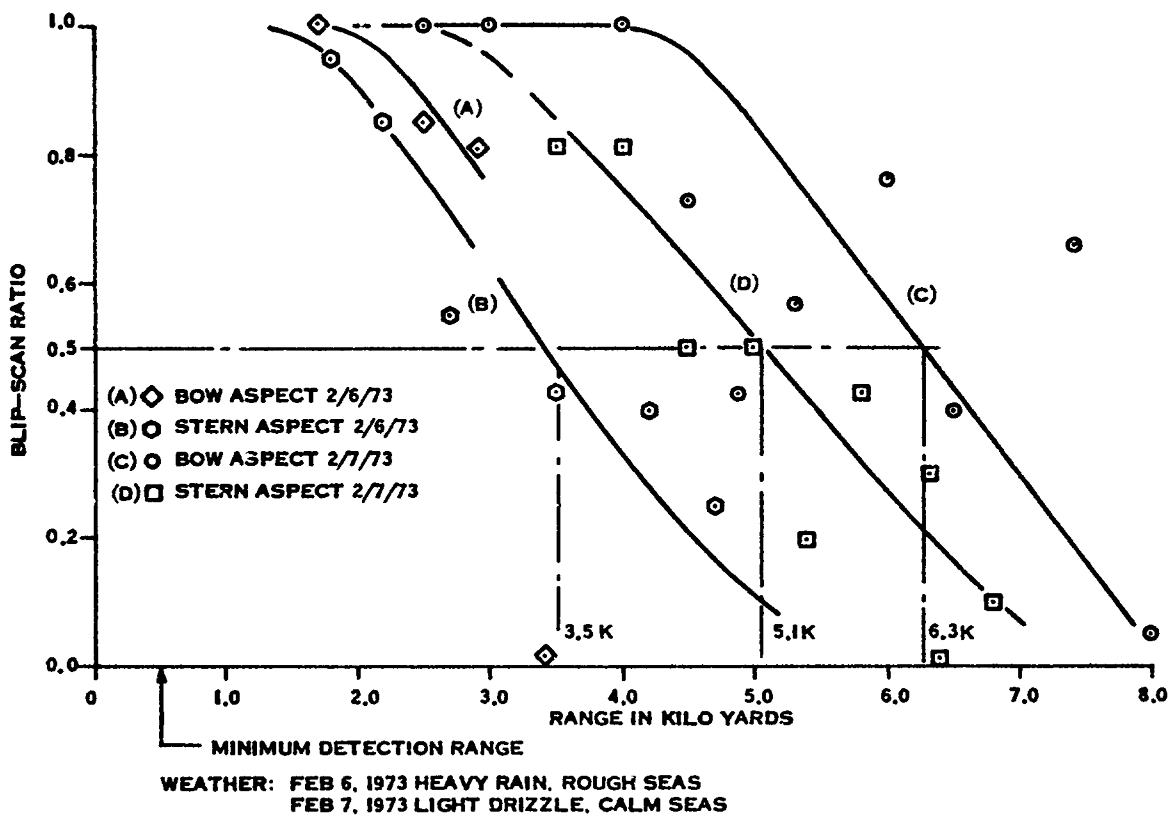

FIGURE 4-6. HAR radar tracking 40-foot cutter during heavy rain.

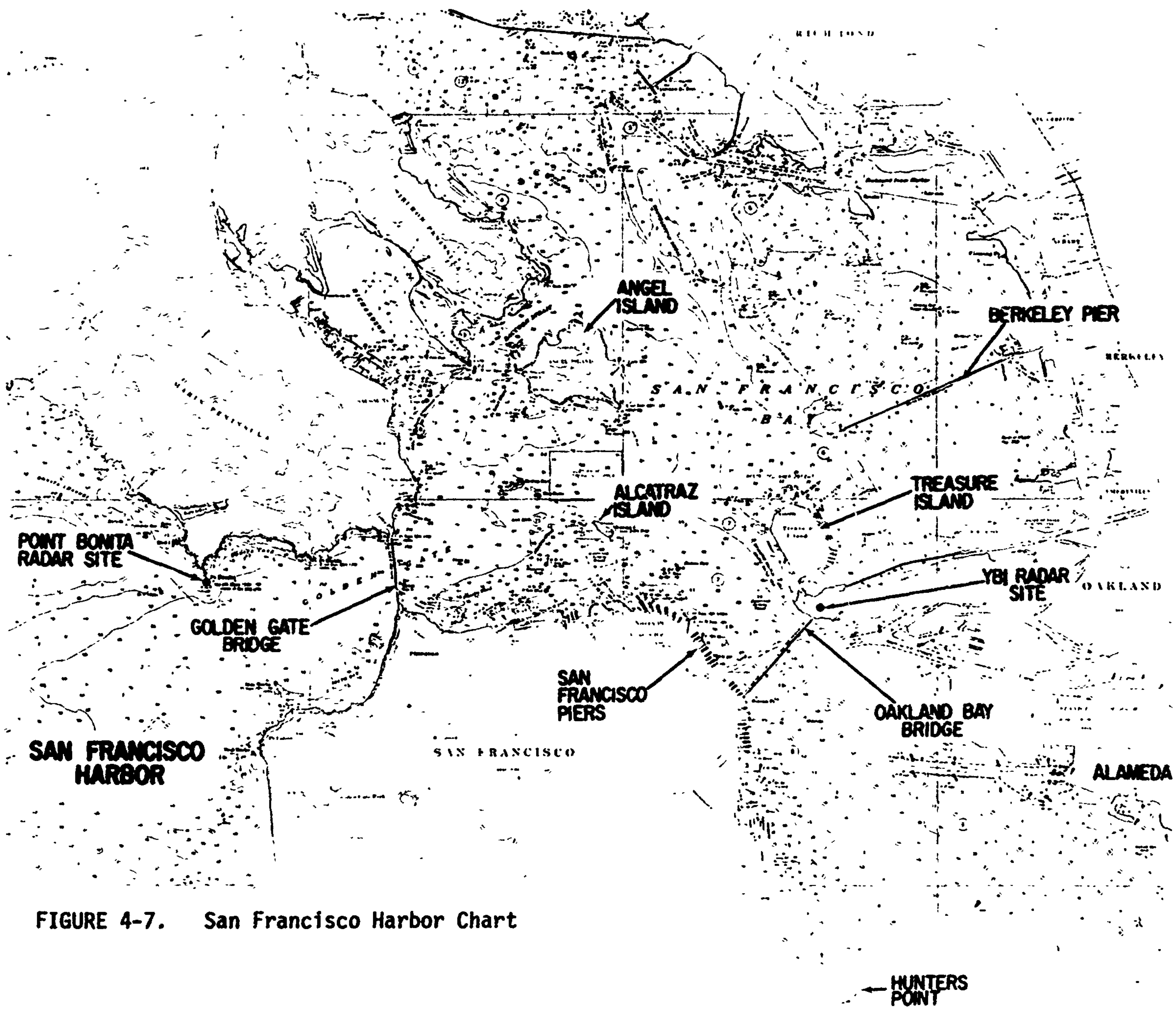

FIGURE 4-7. San Francisco Harbor Chart

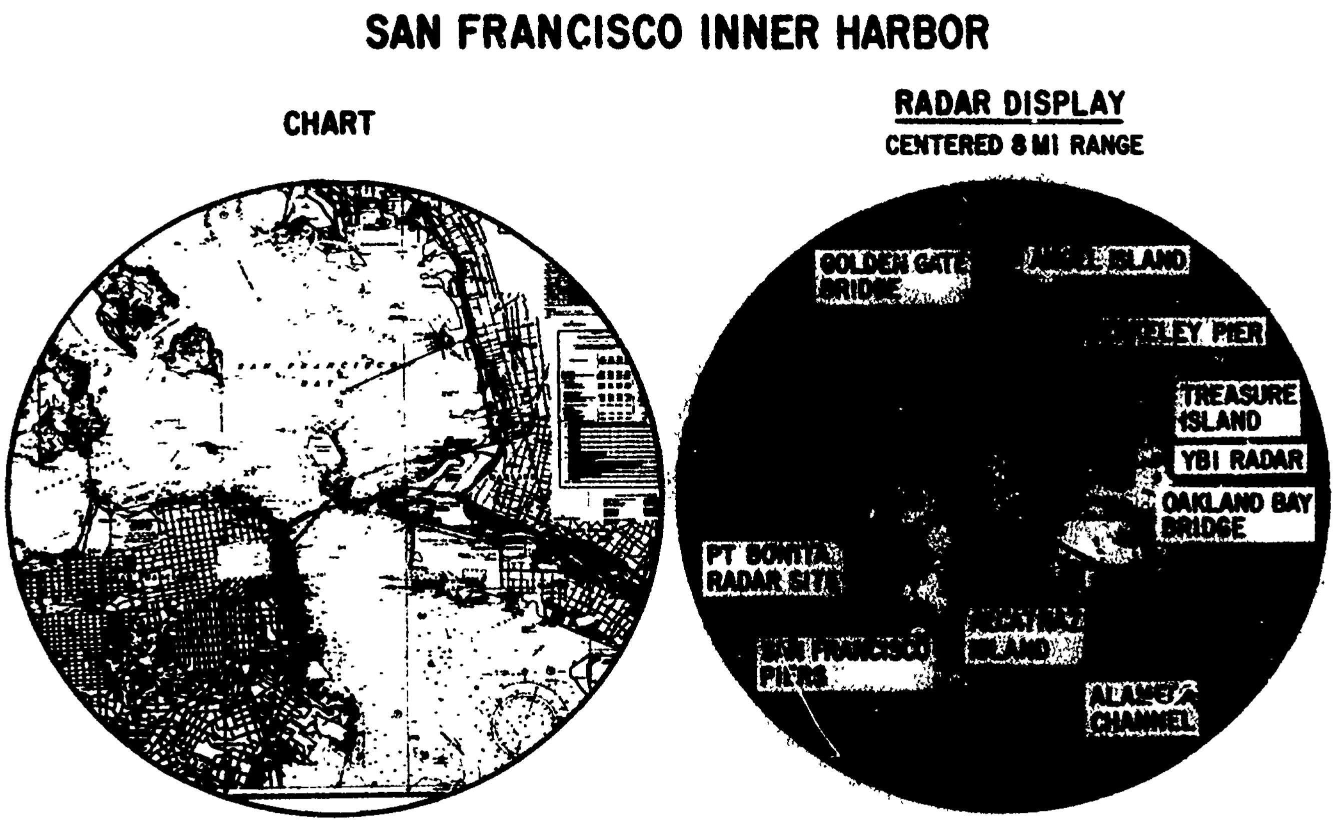

FIGURE 4-8 Scope display orientation

Figure 4-9. PPI display of AIL radar with linear antenna polarization during a rainstorm.

FIGURE 4-10. PPI display of AIL radar with circular antenna polarization during the same rainstorm.

4.3.2 Test I-2, Angle and Range Resolution

4.3.2.1 Angle Resolution. The ability of a radar system to resolve two targets in close proximity is determined by the transmitted pulse length and the antenna beamwidth. Normally, the antenna beamwidth is stated in terms of the angular spread between the one-way 3-dB (or half-power) points of the antenna beam pattern. The 3-dB points correspond to a 6-dB total path loss between transmit and receive. The PPI display will have a 10- to 20-dB dynamic range so that a target return must drop substantially more from its maximum value at beam center than the 6-dB two-way beam pattern attenuation before it becomes invisible on the display. For two contiguous targets, the radar paints a single target if the two targets are not separated by more than a beamwidth in azimuth or by the range resolution increment range-wise. A number of tests were conducted to establish experimentally the effective resolution characteristics of the AIL and HAR radars.

Figure 4-11 shows the results of the tests conducted to determine the angular resolution characteristics of the two radars The targets were two 40-foot cutters in close proximity to each other at the beginning of the event (each event corresponding to a data point). The targets separated, and the radar PPI displays were monitored by the operator. At the moment that the single target spot displayed on the PPI separated into two distinct targets, a signal was given to the cutter crews who measured the separation with a calibrated line. The results shown in Figure 4-11 indicate that the effective beamwidth resolution for the AIL radar was approximately 0.56 degrees and approximately 0.97 degrees for the HAR radar.

The AIL antenna beamwidth between the 3-dB points is 0.3 degree, and the HAR beamwidth is 0.6 degree. The experimental results indicate that the effective resolution beamwidth for the AIL radar is 1.8 times the 3-dB defined beamwidth and 1.6 times the 3-dB defined beamwidth for the HAR radar. The closeness of the ratios is a good indication of the probable reliability of the data. It should be noted that the experimental measurements were restricted to ranges of less than 5000 yards because of the limited detection range of the HAR radar.

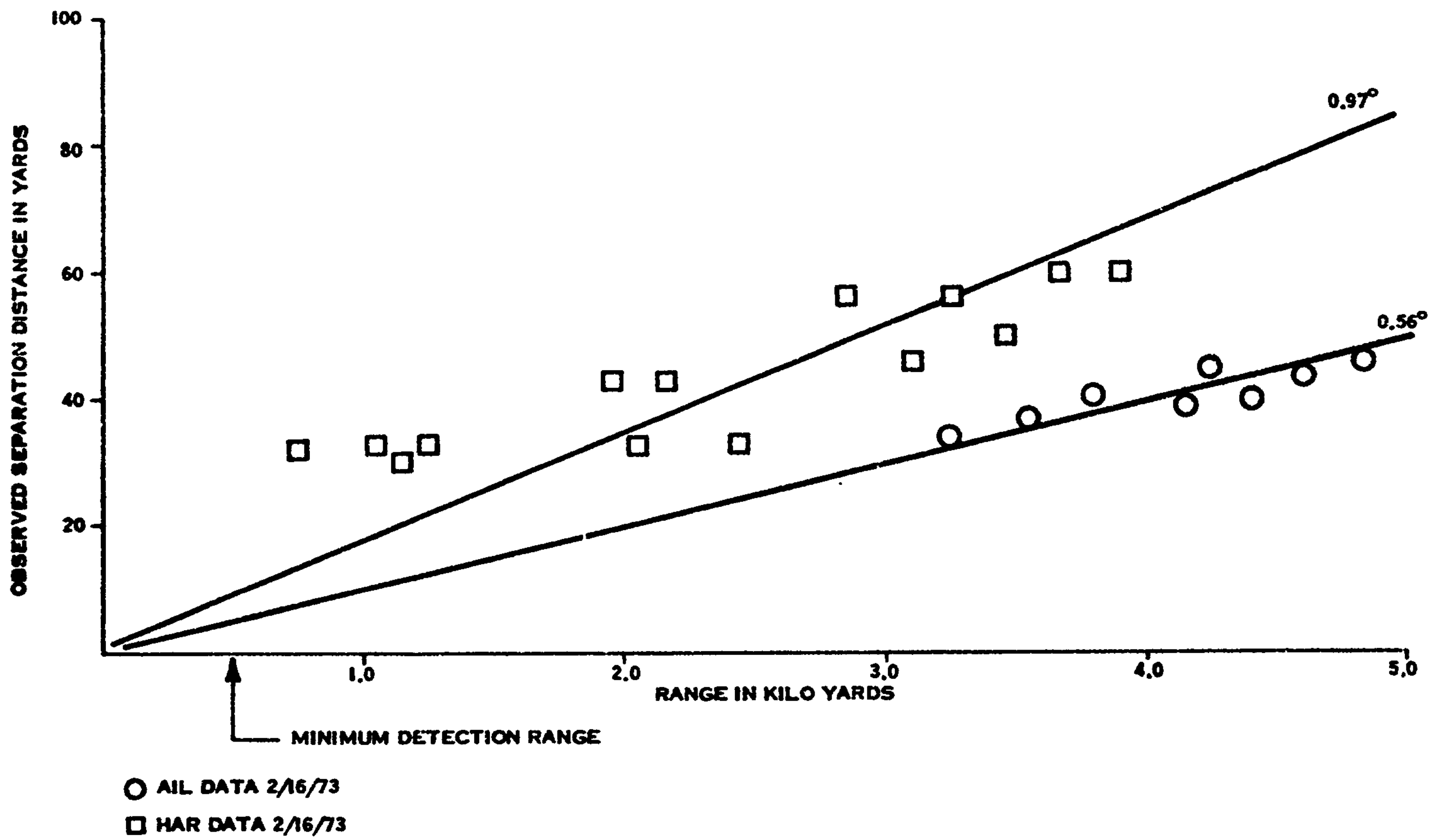

FIGURE 4-11. Angle resolution of AIL and HAR radars.

4.3.2.2 Range Resolution. The results of the range resolution tests performed for the HAR and AIL radars are given in Table 4-1. The test A results were obtained using the wide pulse in both radars (i.e., 200 nanoseconds for the AIL radar and 500 nanoseconds for the HAR radar). The theoretical range resolution for the AIL radar with wide pulse is 32.6 yards, which compares favorably with the observed mean of 53 yards. The theoretical range resolution of the HAR radar with the transmitted wide pulse is 81.5 yards, which compares favorably with the observed 100-yard resolution.

In test B, both radars were operated with a narrow transmitted pulse of 50 nanoseconds, which has a theoretical range resolution of 8.15 yards. Neither radar approached the theoretical value; the AIL radar had an observed mean of 31 yards and the HAR, a mean of 39.2 yards. This inability to demonstrate the theoretical range resolution value was attributed to the CRT resolution limitations that confined resolution to approximately 16 to 20 yards because of the finite spot size and the operator visual accuity. (An A-scope test would very probably have given an observed resolution nearer the theoretical value of 8.15 yards.)

4.3.3 Test I-3, Target Blip (Size) Characteristics

The limiting resolution of a radar (i.e., range and angle resolution) should be ultimately related to the capability of the radar to distinguish, by size, between targets whose dimensions are greater than the resolution limits of the radar. A test was conducted to determine this capability for both the HAR and the AIL radars. Three vessels (a 40-foot cutter, an 82-foot cutter, and a 210-foot cutter) were positioned approximately 2000 to 5000 yards from the radar site of YBI and were separated by a distance sufficient for distinct target indications or blips to be displayed on the radar PPIs. Both beam and stern aspects were were presented to the radars so that the differences in the display for beam and length aspects could be determined.

TABLE 4-1. Range resolution test results for AIL and HAR radars.

Test	Range (Yards)	Resolution (Yards)		Mean Value (Yards)		Comments
		AIL	HAR	AIL	HAR	
A	5040	70				AIL pulse width: 200 nanoseconds; HAR pulse width: 500 nanoseconds; range scale for both radars: 8.0 nmi
	5200		100			
	5360	50				
	5400	50	100			
	5600	45				
	5800	50				
				53	100	
B	3560		40			Pulse width for both radars: 50 nanoseconds; range scale for both radars: 4.0 nmi
	3720		42			
	3940		33			
	4420	30				
	4520	23				
	4700		33			
	8260	20				
	8620	22				
	8660	20				
	10,000	63				
	10,020	50				
				31	39.2	

Figures 4-12 and 4-13 present photographs of the PPI display on the 8.0-nmi range scale for the HAR and AIL radars, respectively, when the three cutters were presenting a beam aspect at a range of 5000 yards. The three blips on the HAR display were barely distinguishable from one another. The AIL radar display indicated a blip

FIGURE 4-12. PPI display of HAR radar showing blip size comparison on 8.0-nmi range scale for beam aspect of targets (82-, 210-, and 40-foot cutters) at 306 degrees, 5000 yard range.

size for the 40-foot cutter that was approximately one-half the diameter of the blips for the other two cutters. Also, it should be noted that the HAR radar did not detect the 40-foot cutter on every scan as did the AIL radar; therefore, an operator could infer from this type of behavior of the target return that the target was a smaller vessel.

FIGURE 4-13. PPI display of AIL radar showing blip size comparison on 8.0-nmi range scale for beam aspect of targets (82-, 210-, and 40-foot cutters) at 304 degrees, 4960-yard range.

Figures 4-14 and 4-15 present photographs of the PPI displays on the 4.0-nmi range scale for the HAR and AIL radars, respectively, when the three cutters were presenting a stern aspect at a range of approximately 3700 yards for the HAR radar and 4960 yards for the AIL radar. The HAR radar (Figure 4-14) display indicated only two targets (the 82-foot cutter and the 210-foot cutter), with the 40-foot cutter having faded out. The return from the 210-foot cutter is at least twice as

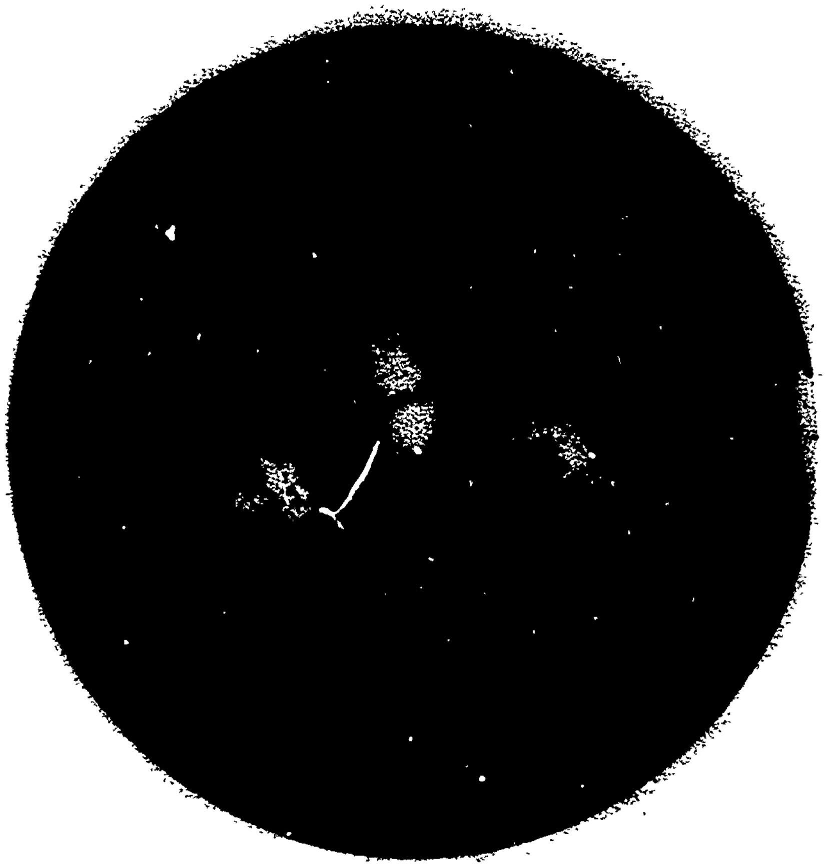

FIGURE 4-14. PPI display of HAR radar showing blip size comparison on 4.0-nmi range scale for stern aspect of targets (82-, 210-, and 40-foot cutters) at 302 degrees, 3700-yard range.

large as that of the 82-foot cutter. In Figure 4-15, all three target returns are visible, with the return from the 210-foot cutter being larger than that of the 82-foot cutter and the return from the 82-foot cutter being much larger than that from the 40-foot cutter. It should be noted that the AIL PPI display also indicated many other returns and the riptide extending around YBI.

FIGURE 4-15. PPI display of AIL radar showing blip size comparison on 4.0-nmi range scale for stern aspect of targets (82-, 210-, and 40-foot cutters) at 304 degrees, 4960-yard range.

Figures 4-16 and 4-17 present photographs of the AIL PPI on the 2.0-nmi range scale, Figure 4-16 showing the target echo return for the beam aspect at 5120 yards and Figure 4-17 showing the target echo return for the stern aspect of the three cutters at 4400 yards. A comparison of these photographs indicates a distinct change in the characteristic of the return blip size for the 210-foot cutter between stern and beam aspects. The blip is oblong in both photographs, indicating that the ship is much larger than the resolution cell

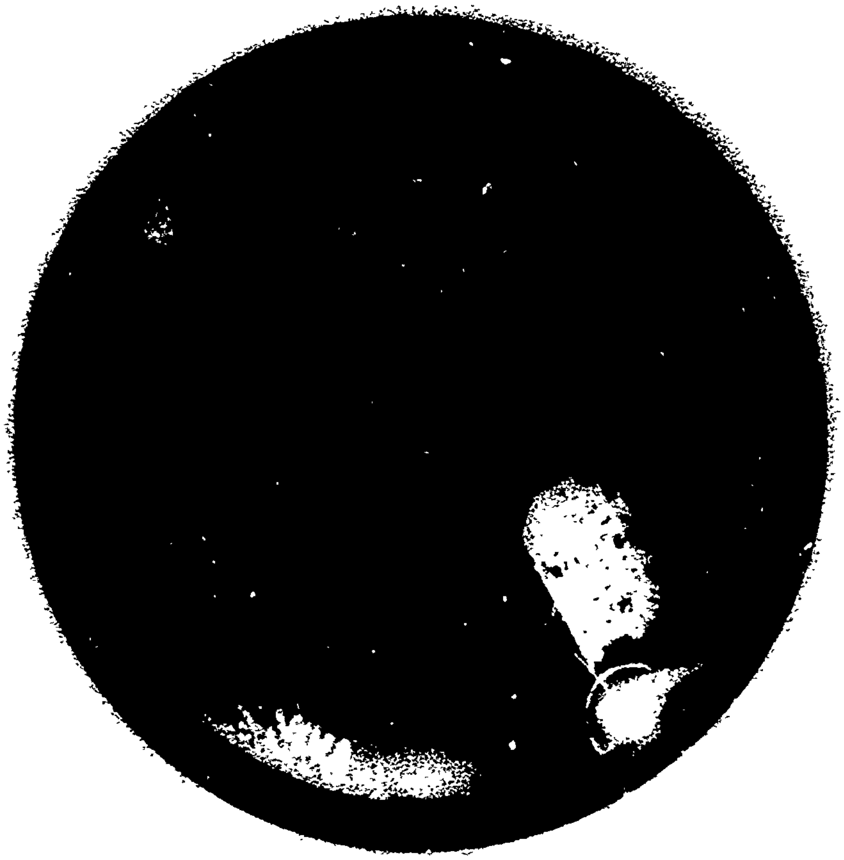

FIGURE 4-16. PPI display of AIL radar showing blip size comparison on 2.0-nmi range scale for beam aspect of targets (92-, 210-, and 40-foot cutters) at 315 degrees, 5120-yard range.

size of the radar at the range of the test. A comparison of Figures 4-16 and 4-17 also indicates that the target blip appears to rotate 90 degrees, corresponding with the known fact that the ship has rotated 90 degrees relative to the radar. The difference between the stern and beam aspects of the 82-foot and the 40-foot cutters is not as distinctive, with no apparent change in the characteristics from beam to stern aspect.

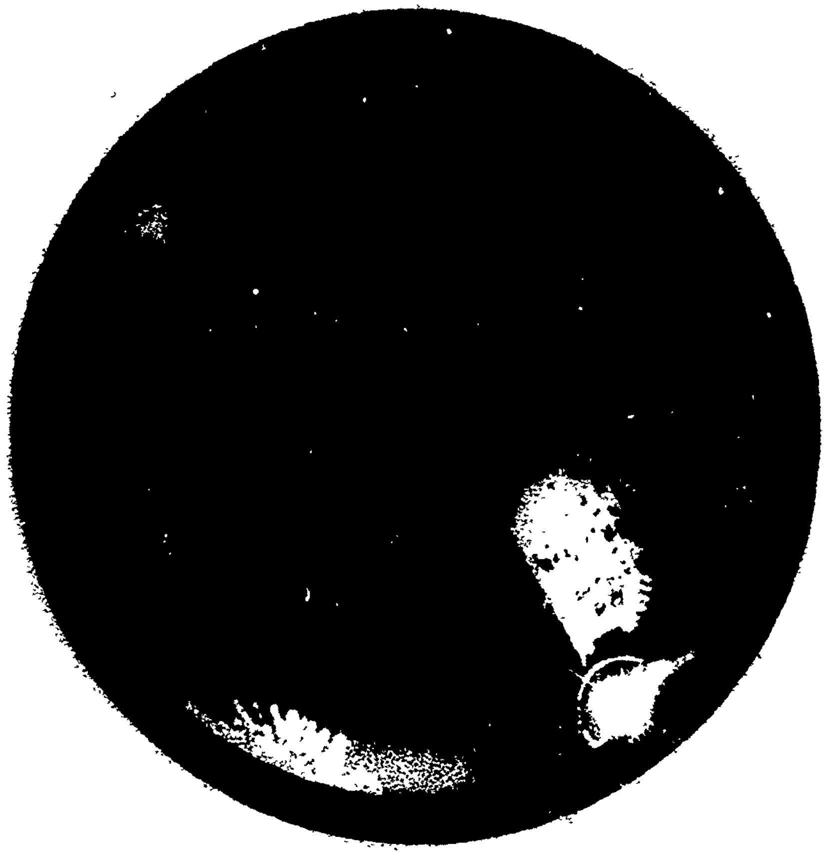

FIGURE 4-17. PPI display of AIL radar showing blip size comparison on 2.0-nmi range scale for stern aspect of targets (82-, 210-, and 40-foot cutters) at 303 degrees, 4400-yard range.

4.4 TEST II, DYNAMIC TARGETS

4.4.1 Test II-1, Pier and Target Resolution and Test II-2, Alameda Estuary and Passing Targets

The resolution capabilities of the AIL radar are shown in Figure 4-18, which is a photograph of the PPI on the 2.0-nmi range scale. It will be observed that the San Francisco piers are very well delineated.

FIGURE 4-18. PPI display of AIL radar on 2.0-nmi range scale (one scan of radar with linear antenna polarization).

The AIL PPI display on the 4.0-nmi range scale is shown in Figure 4-19. This photograph was made with time-lapse technique and indicates the track of several targets traversing the bay area, a small boat approaching an anchored vessel just to the west of the northern end of Treasure Island, and a vessel traversing the Oakland Inner Harbor channel. (It should be noted that these photographs do not completely capture the capabilities of the AIL PPI display since there is some degradation in photographing the display and in the subsequent reproduction processes.)

FIGURE 4-19. Time lapse photograph of PPI display of AIL radar with centered 4.0-nmi range scale. Twelve successive exposures were made at approximately 1-minute intervals to indicate ship movements. (Note, for example, the small boat approaching the vessel at anchorage.)

Figure 4-20 is a photograph of the AIL PPI display on the 8.0-nmi range scale, indicating the detail available throughout the bay region.

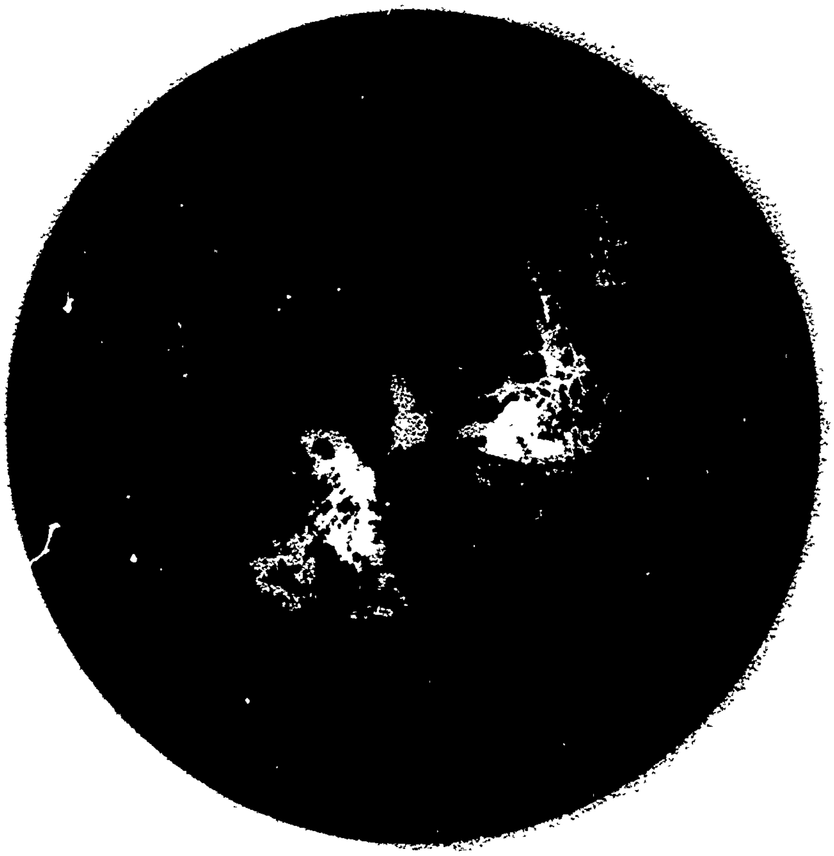

FIGURE 4-20. PPI display of AIL radar on 8.0-nmi range scale (one scan of radar with circular antenna polarization being used to reduce rain clutter return).

Figure 4-21 presents a photograph of the HAR PPI display with the 8.0-nmi range scale. A comparison of this photograph with Figure 4-20, which presents the AIL radar display with the 8.0-nmi scale, indicates that the Berkeley Pier and the Naval Air Station are presented in considerable detail on the AIL display; whereas, the HAR display lacks the definitive presentation of the pier and the Naval Air Station runways.

FIGURE 4-21. PPI display of HAR radar on 8.0-nmi range scale (one scan of radar).

The HAR PPI display with the 2.0- and 4.0-nmi range scales is illustrated in Figure 4-22 and 4-23. A comparison of these photographs with Figure 4-19, which shows the AIL display with the 4.0-nmi scale, indicates that the Alameda Naval Air Station runways are displayed in some detail by the AIL display and are almost totally missing from the HAR display. Similarly, the Berkeley Pier is shown as a solid return throughout its length on the AIL display and presents no return on the HAR display. The degradation of the HAR radar was attributed to the basic poorer performance capability of the HAR radar.

FIGURE 4-22. PPI display of HAR radar on 2.0-nmi range scale (one scan of radar).

4.5 TEST III, WEATHER TESTS

4.5.1 Test III-1, Sea Clutter Suppression With Antenna Polarization and Test III-2, Rain Suppression With Antenna Polarization

The results of these tests were combined with the results of the Range Detection tests and were discussed previously in Paragraph 4.3.1.1.

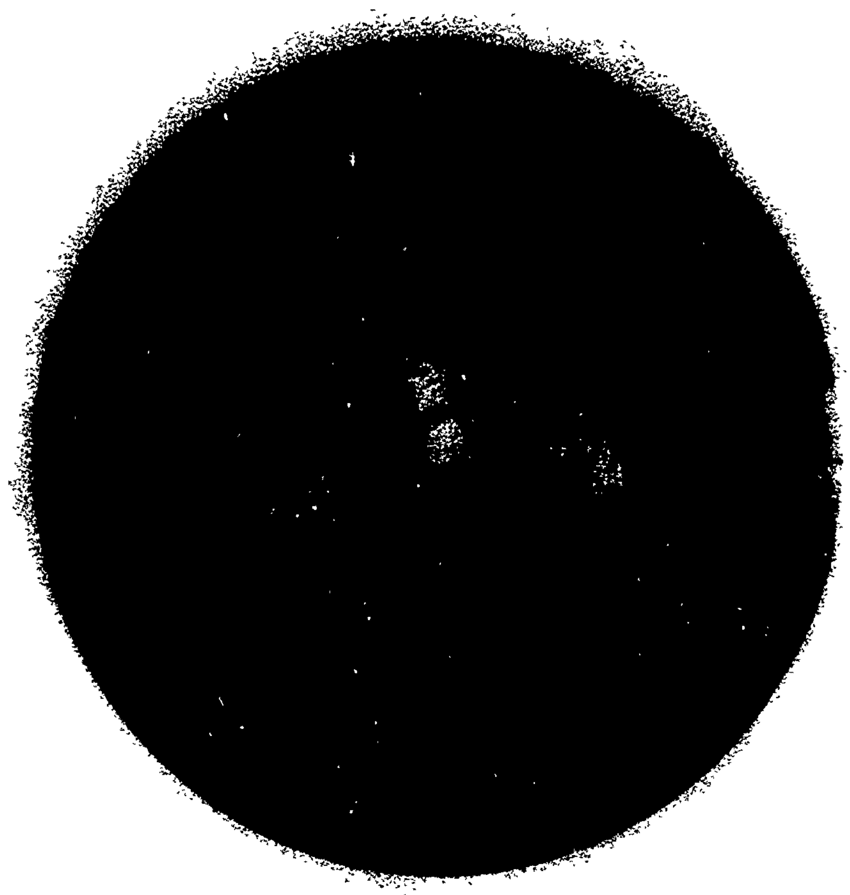

FIGURE 4-23. PPI display of HAR radar on 4.0-nmi range scale (one scan of radar).

4.5.2 Test III-3, Clutter and Rain Suppression With STC and FTC Modes

This test was conducted to determine the effectiveness of the FTC in minimizing sea clutter on the PPI presentations of the HAR and AIL radars. Figure 4-24 and 4-25 present photographs of

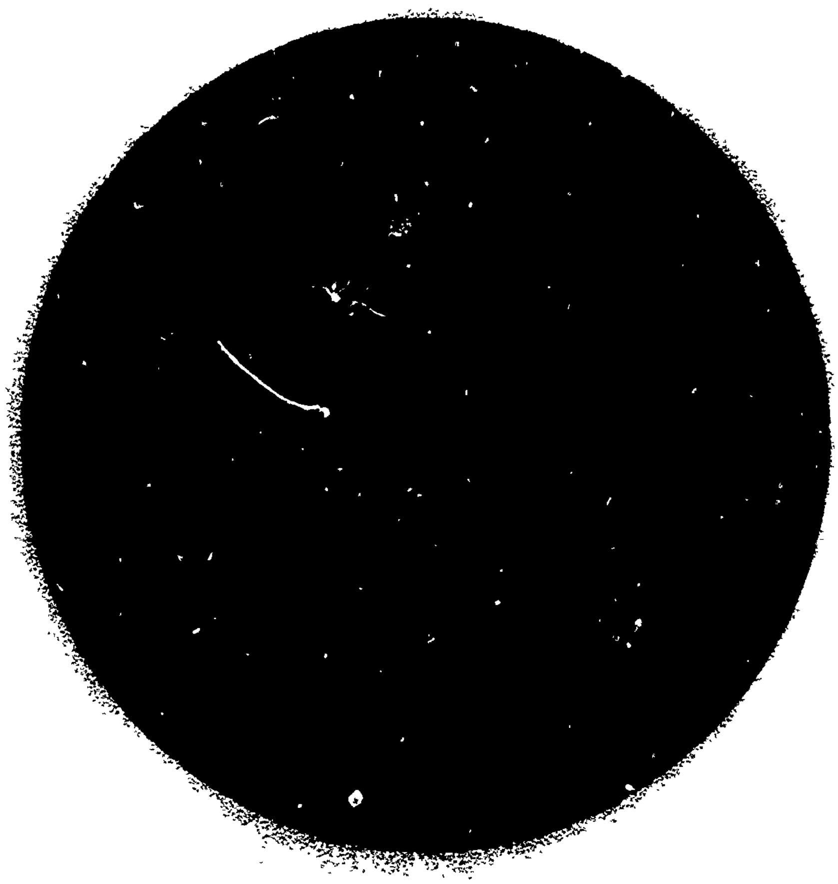

FIGURE 4-24. PPI display of AIL radar with FTC tracking 40-foot cutter at 190 degrees, range of 2300 yards in a local rainstorm.

the PPI display of the AIL radar with FTC on and off, respectively. These photographs were made during a local rain storm. The radar was tracking a 40-foot cutter that reported a 3- to 4-foot chop. A comparison of these figures indicates that the FTC mode definitely reduced the PPI clutter and made the targets more visible.

FIGURE 4-25. PPI display of AIL radar without FTC tracking 40-foot cutter at 190 degrees, range of 2300 yards in a local rainstorm.

Figures 4-26 and 4-27 present photographs of the PPI display of the HAR radar at approximately the same time as the previous photograph. The effectiveness of the FTC mode for the HAR radar was not as significant as that for the AIL, primarily because of the reduced

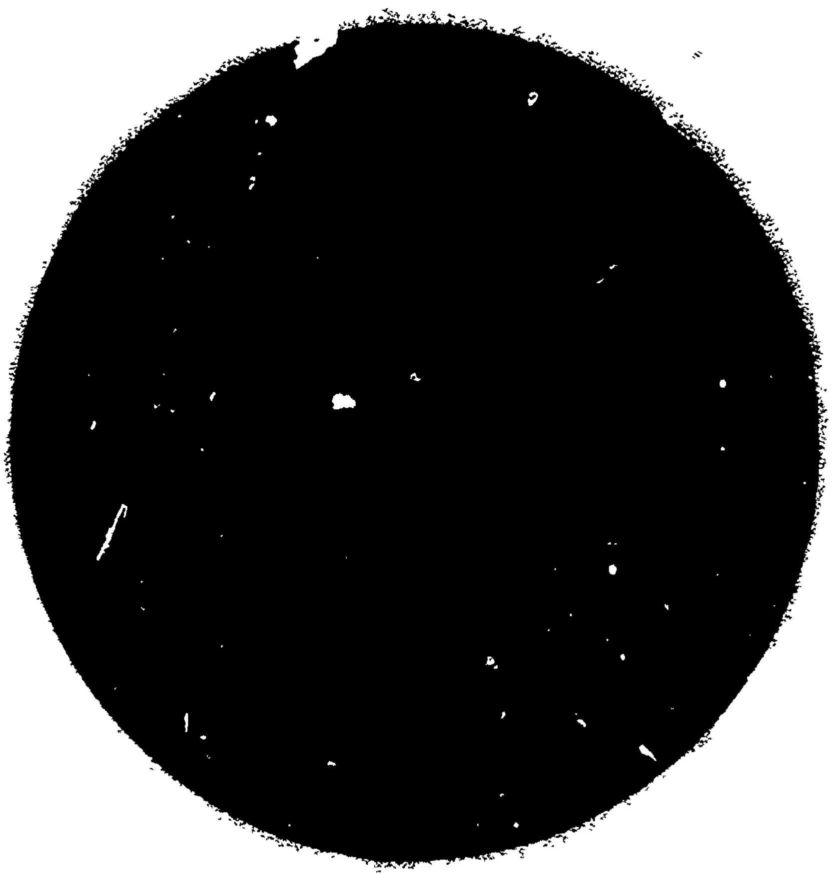

FIGURE 4-26. PPI display of HAR radar with FTC tracking 40-foot cutter at 180 degrees, range of 1900 yards in a local rainstorm.

range capability of this radar. The reduced sensitivity of the HAR radar as compared with the AIL radar is shown by comparing Figures 4-25 and 4-27 in which the FTC is off for both radars. The HAR radar did not detect the presence of sea clutter much beyond the edge of YBI.

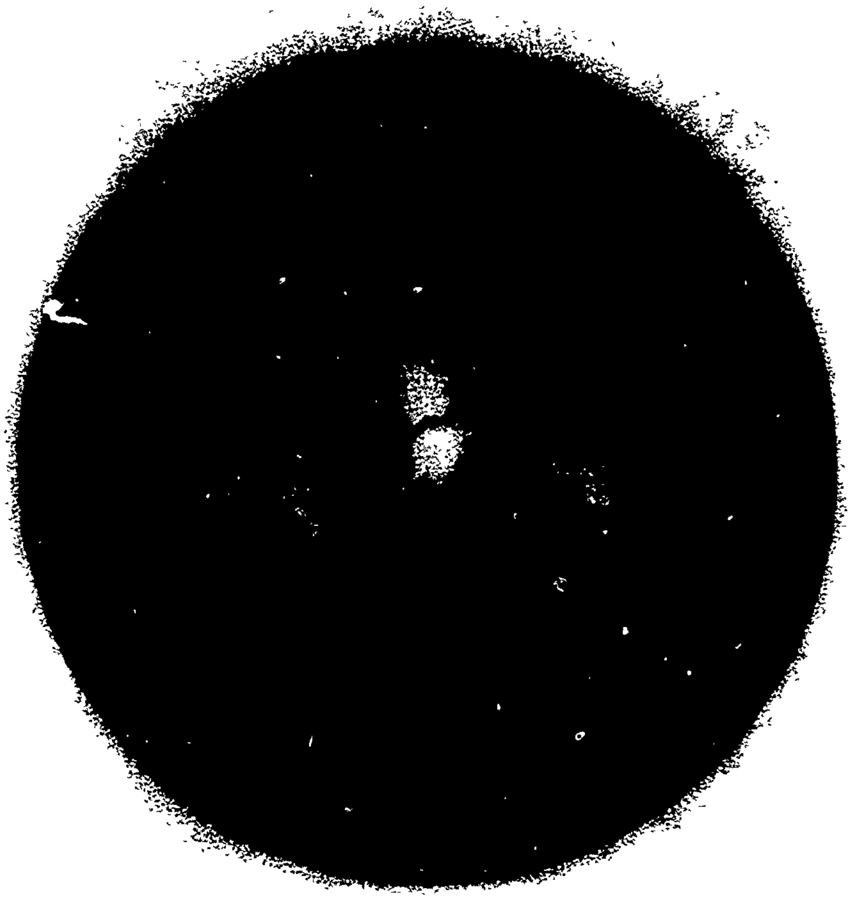

FIGURE 4-27. PPI display of HAR radar without FTC tracking 40-foot cutter at 191 degrees, range of 2300 yards in a local rainstorm.

Figures 4-28 through 4-37 show the effect of using the STC on the PPI presentations in the presence of clutter for the HAR and the AIL radars. The photographs of the two PPIs were made at approximately the same time, during a period of moderate clutter.

FIGURE 4-28. PPI display of HAR radar with STC - 4.0-nmi range scale.

Figures 4-28 and 4-29 illustrate the difference in PPI appearance on the HAR radar on the 4.0-nmi scale with and without maximum STC. It should be noted that the STC reduced the close-in clutter return considerably, making close-in targets more detectable.

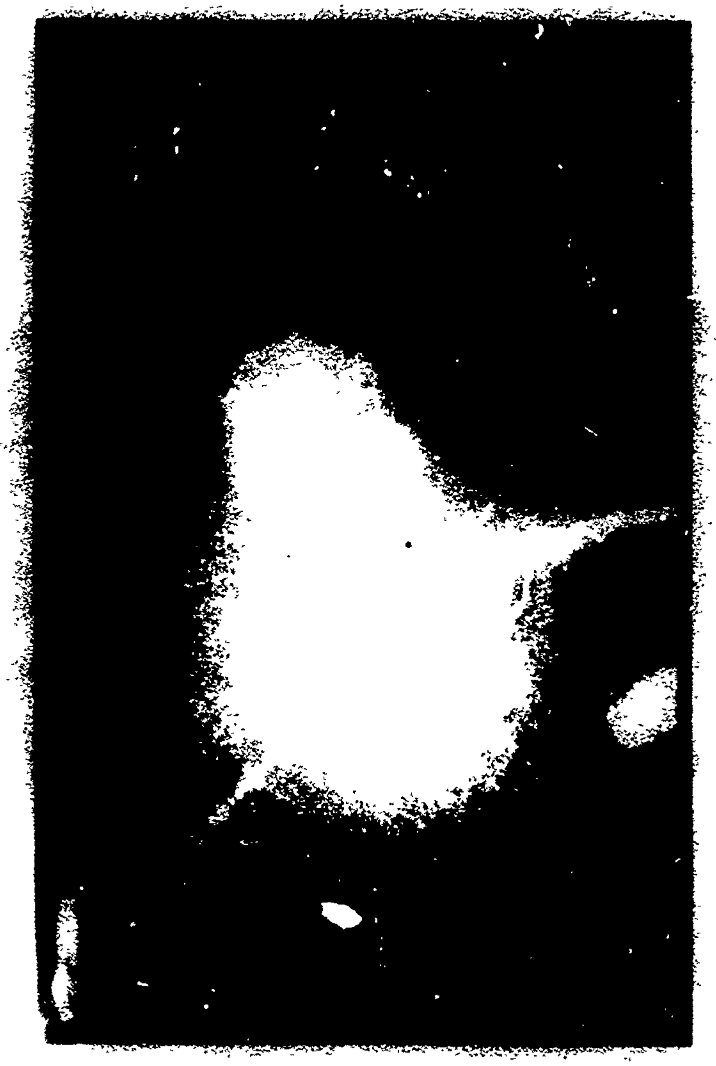

FIGURE 4-29. PPI display of HAR radar without STC - 4.0-nmi range scale.

Figures 4-30 through 4-33 present photographs of the AIL PPI with and without STC on the 4.0-nmi scale. Figure 4-30 shows the AIL PPI presentation without STC and illustrates that close-in clutter saturates the display. In Figure 4-31, the AIL STC control was set to the 1 position. The close-in clutter was effectively suppressed. In Figure 4-32, the AIL STC control was set to position 2

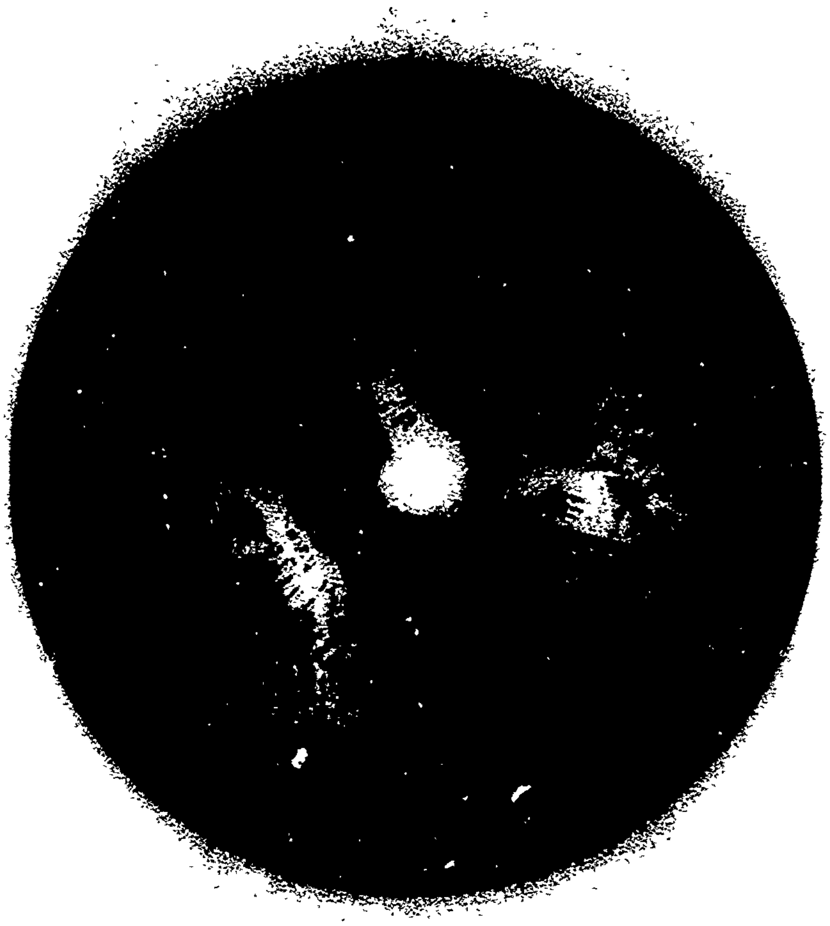

FIGURE 4-30. PPI display of AIL radar (linear antenna polarization) without STC - centered 4.0-nmi range scale.

and almost all the clutter disappeared from the display. This photograph also illustrates an obvious reduction in the amplitude of the return from the San Francisco piers as well as from the Oakland Inner Harbor channel region. In Figure 4-33, the STC control was set to position 3, and the return for the entire display has been essentially obliterated.

FIGURE 4-31. PPI display of AIL radar with STC set to position 1 - centered 4.0-nmi range scale.

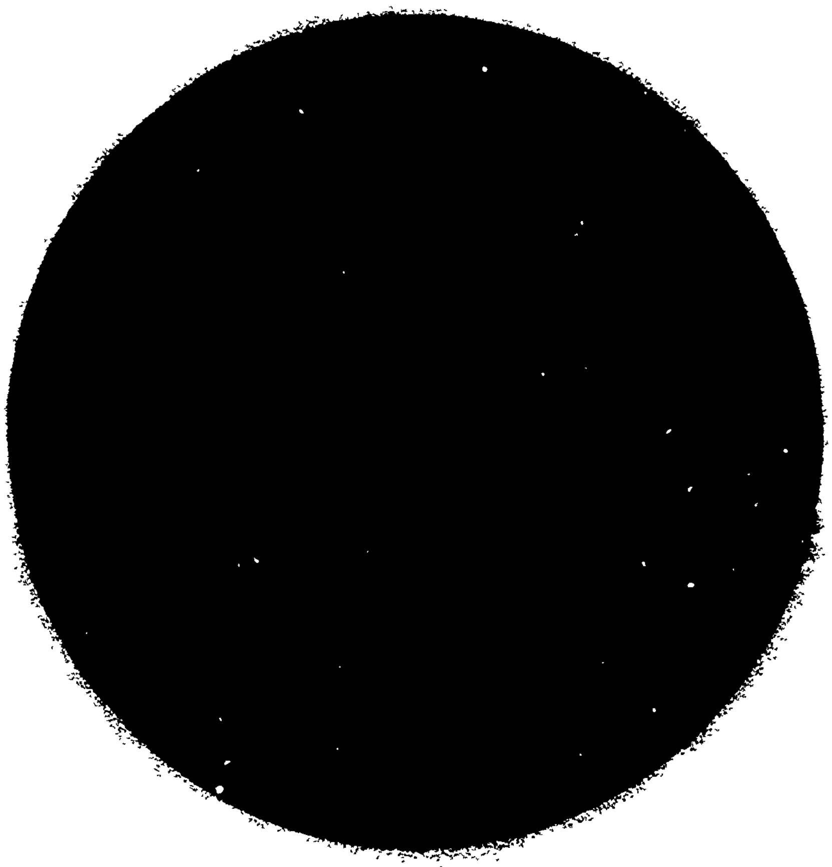

FIGURE 4-32. PPI display of AIL radar with STC set to position 2 - centered 4.0-nmi range scale.

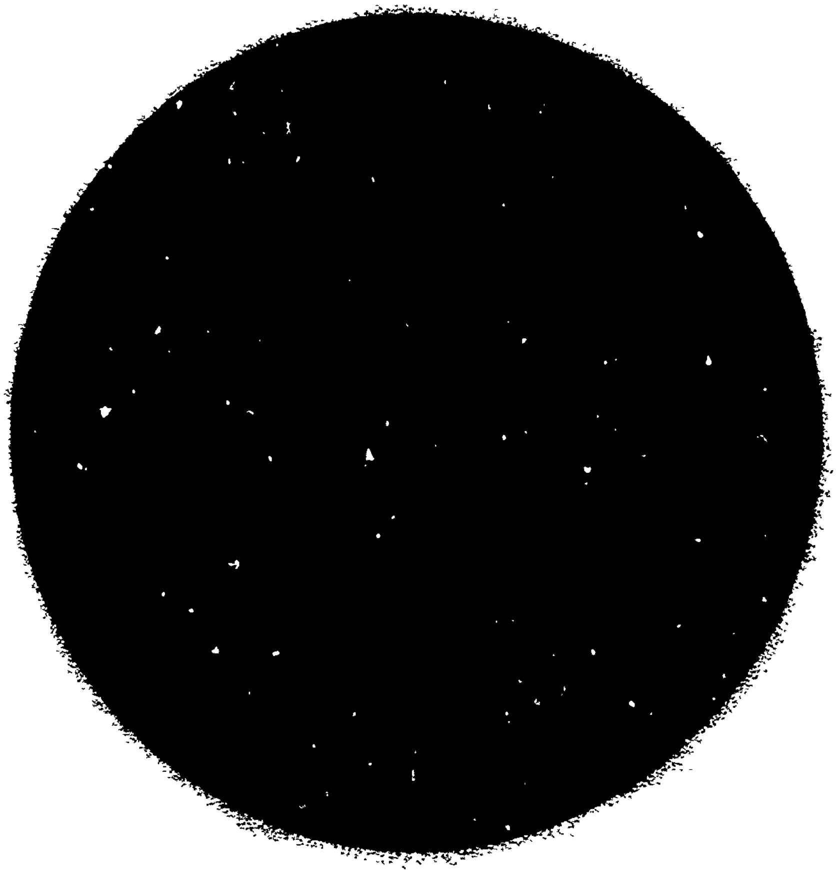

FIGURE 4-33. PPI display of AIL radar with STC set to position 3 - centered 4.0-nmi range scale.

Figures 4-34 through 4-37 are photographs of the AIL PPI display on the 8.0-nmi scale with and without STC. Figure 4-34 presents a photograph of the PPI without the STC being used. This figure shows that close-in clutter saturates the central portion of the PPI. The STC was set to position 1 (Figure 4-35), and very close-in clutter was removed from the display with little effect on the clutter at

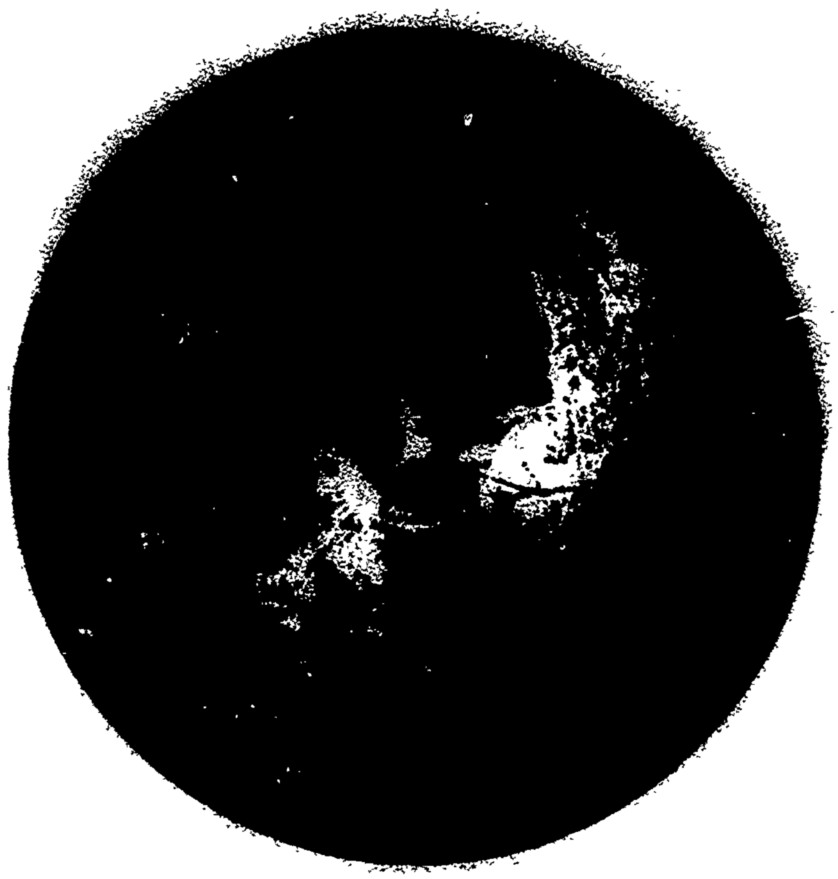

FIGURE 4-34. PPI display of AIL radar (linear antenna polarization) without STC - 8.0-nmi range scale.

longer ranges. When the STC was set to positin 2 (Figure 4-36), the close-in clutter, the clutter at 2 to 3 nmi, and the return from Treasure Island were suppressed. Figure 4-37 shows the display when the STC was set at position 3. The return from the total display was suppressed, which was an unsatisfactory condition.

FIGURE 4-35. PPI display of AIL radar (linear antenna polarization) with STC set to position 1 - 8.0-nmi range scale.

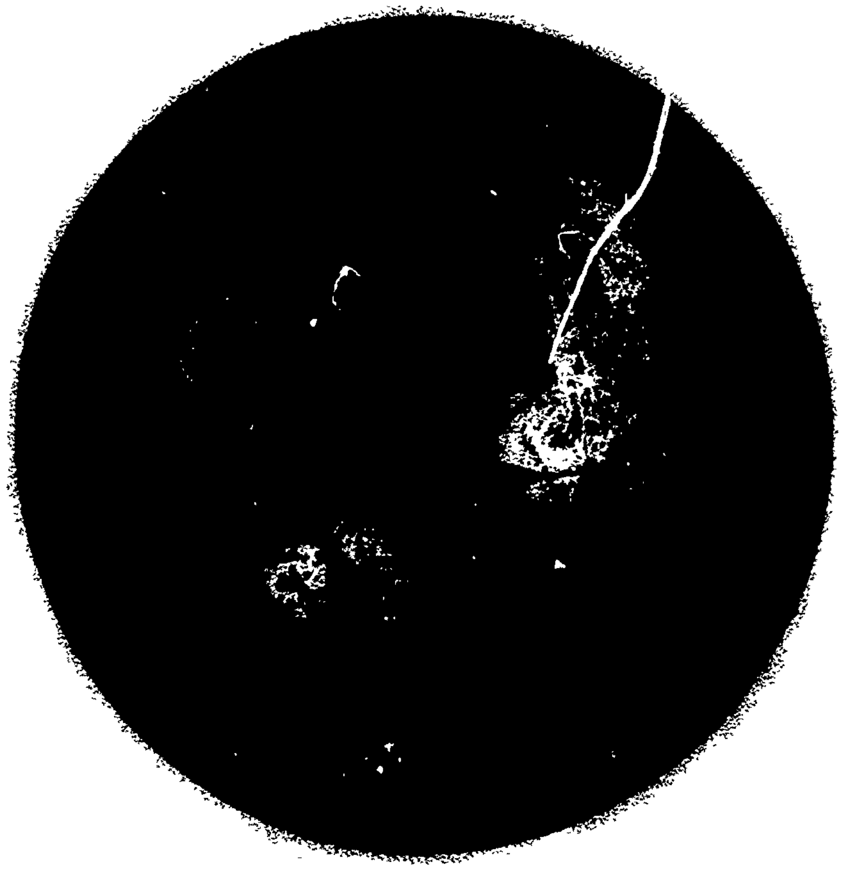

FIGURE 4-36. PPI display of AIL radar (linear antenna polarization) with STC set to position 2 - 8.0-nmi range scale.

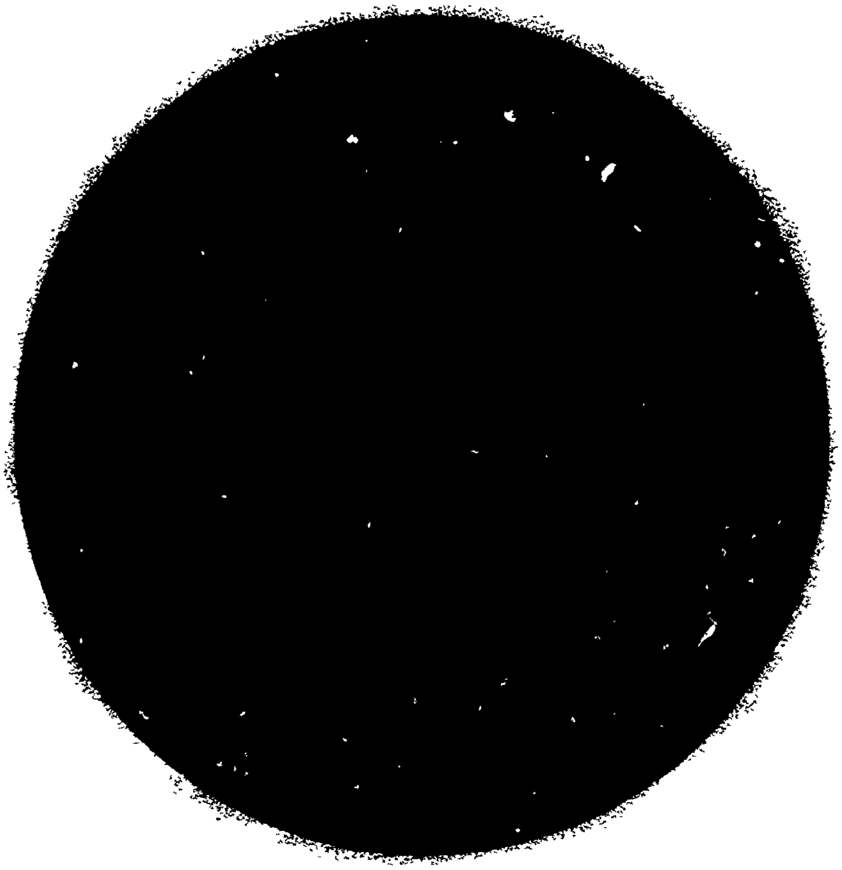

FIGURE 4-37. PPI display of AIL radar (linear antenna polarization) with STC set to position 3 - 8.0-nmi range scale.

4.6 TEST IV, PPI STABILITY

Only a qualitative evaluation of the PPI stability was conducted during the test period because engineering modifications were scheduled for later in the test period and the CRTs, which had manufacturing defects, were scheduled to be replaced. Prior to the engineering modifications, it was observed that the variable range and bearing cursor was cyclically unstable, appearing to move relative to the PPI display in synchronism with the scan. After the modfiication, this effect was eliminated, and qualitatively, the display could be described as very stable. More definitive measurements were not made because of the defective CRTs. The defect appeared to be caused by control grid emission. A second fault that was probably related to the control grid problem, was the appearance of four unfocused spots, displayed symmetrically at approximately 45, 135, 225, and 315 degrees at a distance of approximately one-third the tube radius from the center for any range scale setting or any PPI offset.

4.7 TEST V, SHADOWED AREAS

4.7.1 YBI Shadow Zone for HAR Radar

A plot of the observed shadow zone for the HAR radar of YBI is presented in Figure 4-38. This data was obtained while the radar was tracking a 40-foot cutter as it traversed the area.

Each point on the contour of Figure 4-38 represents a point at which the target either disappeared on a traverse into the shadowed zone or emerged from the shadowed zone.

4.7.2 Alcatraz Island and YBI Shadow Zone for AIL Radar

The Alcatraz Island and YBI shadowed zone for the AIL radar located at YBI is illustrated in Figure 4-39, where the shadowed zone for the HAR radar is plotted for comparison. The data for the HAR radar shadowed zone of Alcatraz Island was not considered sufficient because of the limited range coverage of the HAR radar. Figure 4-40 is a photograph of the AIL radar PPI display taken during a rainstorm which shows the AIL radar shadowed zone of YBI by the appearance of regions of no rain clutter return. It will be seen to compare favorably with the plot in Figure 4-39.

The reduced area of the YBI shadowed zone for the AIL radar was attributed to the greater height of the AIL radar antenna (i.e., obstructions such as trees and terrain in front of the radar antenna producing a smaller geometric shadow).

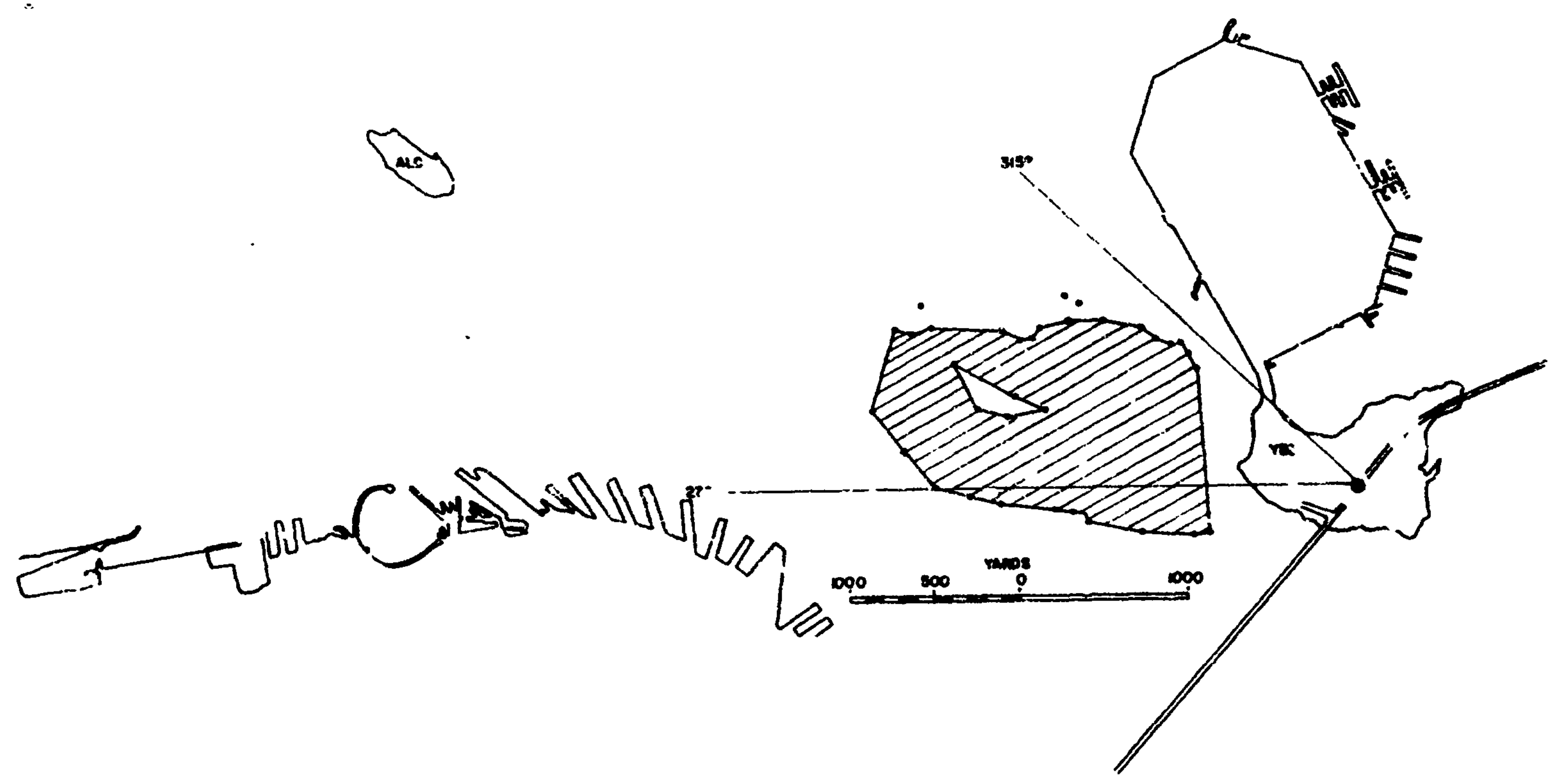

FIGURE 4-38. HAR radar shadow of YBI.

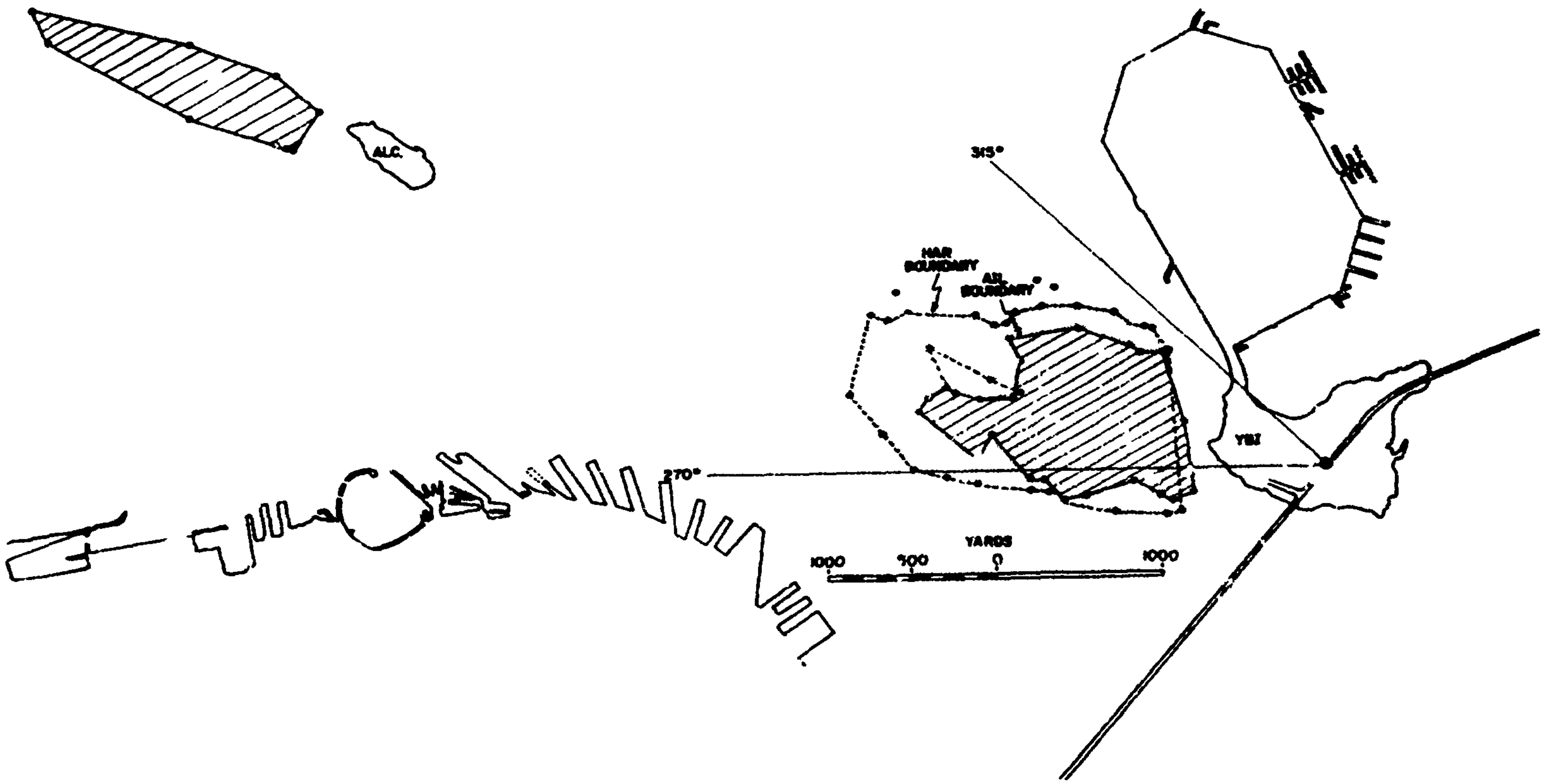

FIGURE 4-39. Shadow comparison of HAR and AIL radars for Alcatraz Island and YBI.

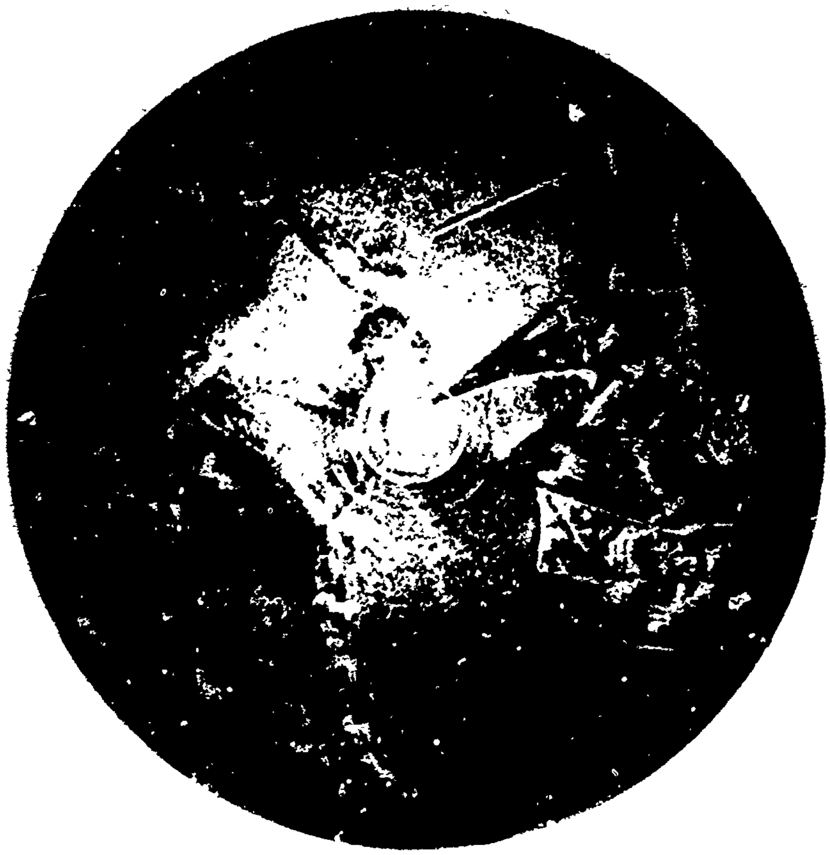

FIGURE 4-40. PPI display of AIL radar shadow areas.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 GENERAL

This section presents the major conclusions of the Comparison Test of the HAR and the AIL radars.

5.2 RADAR PARAMETERS CHECK

The conclusion that can be drawn from the daily radar parameters check results is that the HAR radar was in poor condition and, by comparison with the AIL radar, in very poor condition. The deficiencies of the HAR radar were most obvious in the tests that were conducted to determine the maximum detection range of the radars.

5.3 TEST I, NORMAL RADAR MODES/CLEAR ENVIRONMENT

5.3.1 TEST I-1, Range Detection

5.3.1.1 Maximum Range. The AIL radar maximum detection range for the same target and weather condition as that of the HAR radar was observed to be five to six times greater than the HAR. For moderate to good weather conditions, the AIL radar with narrow pulse transmission and linear polarization displayed a maximum detection range of 32,000 yards while tracking a 40-foot cutter. With circular polarization, the maximum detection range for the HAR radar for the same weather conditions and operating with wide pulse was 5000 to 6000 yards while tracking a 40-foot cutter. Maximum detection ranges of 9000 yards were obtained with the HAR radar tracking a 56-foot tug and 13,000 yards while tracking an 82-foot cutter.

The maximum detection range of the AIL radar in heavy rain and clutter conditions was not determined because the cutter crew requested a termination of the test due to rough seas. A range of 16,000 yards was obtained before termination of the test, with good performance in both circular and linear polarization.

The maximum detection range of the HAR radar for the same test was approximately 3500 yards.

5.3.1.2 Minimum Range. Both the AIL and the HAR radars were observed to have minimum detection ranges of approximately 500 to 600 yards.

5.3.2 Test I-2, Angle and Range Resolution

5.3.2.1 Angle Resolution. The observed angle resolution of the AIL radar was 0.56 degrees, approximately 1.8 times the 3-dB beamwidth of the antenna. The observed angle resolution of the HAR radar was 0.97 degrees, approximately 1.6 times the nominal 3-dB beamwidth of the antenna. (These observed values are the effective beamwidth after processing through the PPI display and may be somewhat less at the video level because the finite CRT spot size sets a lower limit on observable resolution.)

5.3.2.2 Range Resolution. The observed range resolution for the AIL radar with narrow pulse transmission (50 nanoseconds) was 31 yards, nearly four times the theoretical resolution of 8.15 yards. The degradation is attributed to less than optimum video amplifier bandwidth, which tends to stretch the pulse and the finite CRT spot size.

The observed range resolution for the HAR radar with the narrow pulse transmission (50 nanoseconds) was 39 yards, which is poorer than the theoretical value for essentially the same reasons as given for the AIL radar.

The observed range resolution for the AIL radar with wide transmitted pulse (200 nanoseconds) was 53 yards, which compares favorably with the theoretical value of 32.6 yards.

The HAR radar observed range resolution with the wide pulse transmission (500 nanoseconds) was 100 yards, which also compares favorably with the theoretical value of 81.5 yards.

5.3.3 Test I-3, Target Blip (Size) Characteristics

The resolution of the AIL radar was found to be sufficiently great as to permit an operator to estimate the target size for vessels as small as 82 feet. The HAR radar did not exhibit as good a size discrimination capability as the AIL radar. For vessels larger than 200 feet, the HAR displayed a limited capability in size discrimination.

5.4 TEST II, DYNAMIC TARGETS

The resolution capability of the AIL radar is superior to that of the HAR radar as previously discussed in Paragraph 5.3.2.

5.5 TEST III, WEATHER TESTS

5.5.1 Test III-1, Sea Clutter Suppression With Antenna Polarization

No observable attenuation of sea clutter occurred in the AIL radar when polarization of the antennas was switched from linear to circular.

5.5.2 Test III-2, Rain Suppression With Antenna Polarization

In the AIL radar, circular polarization was observed to reduce substantially the clutter return from rainfall. Also, the use of circular polarization was observed to reduce the maximum detection range of the AIL radar from 32,000 to 27,000 yards when the radar was tracking a 40-foot cutter.

5.5.3 Test III-3, Clutter and Rain Suppression With STC and FTC Modes

In both the HAR and the AIL radars, the use of STC and FTC was found useful in reducing sea and rain clutter.

5.6 TEST IV, PPI STABILITY

Engineering modifications to the AIL radar precluded definitive stability tests of the PPI displays.

5.7 TEST V, SHADOWED AREAS

The shadowed area of Alcatraz Island was mapped for the AIL radar; however, the restricted range performance of the HAR prevented a similar effort being made for the HAR radar.

The shadowed area of YBI was mapped for both radars, and the zone for the HAR radar was substantially greater than that for the AIL radar.

5.8 RECOMMENDATIONS

5.8.1 Operator Studies

The San Francisco HAR radar operators have been utilizing an obsolete marine radar for harbor surveillance and will now shift operations to a system capable of displaying a much greater degree of information. Consideration should be given to operator training and information detection, analysis, and interpretation. It is recommended that operator studies be performed to determine possible information filtering and automatic analysis requirements.

5.8.2 Further Evaluation

This evaluation was conducted to determine, from a target detection and display viewpoint, the gross improvement in surveillance capability for the San Francisco VTS. Since an obsolete and poorly performing radar was tested alongside a modern high-resolution radar, the results were as anticipated. Specification for a radar to serve as a standard for Coast Guard harbor surveillance can be based on AN/FPS-109 performance as exhibited to date and to be tested in further technical detail. However, it is recommended that a side-by-side comparison with a modern off-shelf radar and the AN/FPS-109 be conducted to determine performance differences.

APPENDIX A

HAR AND AIL DAILY PARAMETERS

A.1 GENERAL

This appendix presents the procedures that were used in obtaining the daily parameters of the HAR and the AIL radars and the measured values obtained.

A.2 PROCEDURES

A.2.1 Antenna Scan Rate

Over a period of 1 minute, the number of sweep rotations from 000 through 360 degrees and back to 000 degrees were counted. This number was entered in the daily parameters check list.

A.2.2 Pulse Repetition Frequency

Using the test setup illustrated in Figure A-1, a measurement was made of the time between two consecutive pulses, leading edge to leading edge. The time obtained was entered in the daily check list. The specified times were: 1000 microseconds for 1000 pulses per second (pps); 400 microseconds for 2500 pps; and 250 microseconds for 4000 pps.

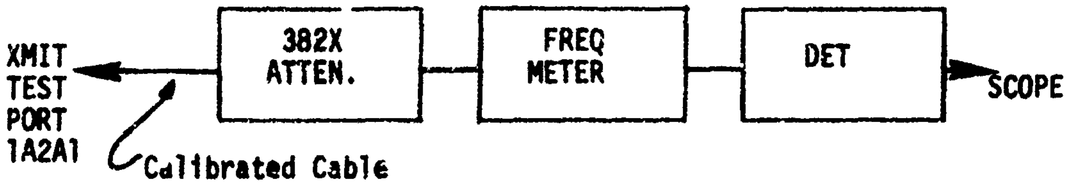

FIGURE A-1. Test setup for PRF/pulse width checks.

A.2.3 Pulse Width

The pulse widths checked included the narrow pulse (50 nanoseconds) and the wide pulse (200 nanoseconds for AIL and 500 nanoseconds for HAR). The procedure used the test setup shown in Figure A-1. The sweep speed on the scope was increased until one detected pulse was observed. Using the 382X attenuator, the attenuation was increased 3 dB and a notation was made of the pink level of the detected pulse. The attenuation was increased by 3 dB and a measurement was made of the pulse with reference to the previous level. This measurement was entered into the daily check list.

A.2.4 Peak Power

The test setup illustrated in Figure A-2 was used to measure the transmitted power. The average power meter reading was converted by using the appropriate duty cycle (Table A-1), coaxial line losses, and coupler value. The peak power value was then entered into the daily check list.

FIGURE A-2. Test setup for peak power check.

TABLE A-1. Pulse width/PRF duty cycles for radars.

Pulse Width/PRF	AIL	HAR
50 nanoseconds at 1000 pps	-43 dB	-43 dB
2500 pps	-39 dB	
4000 pps	-37 dB	-37 dB
200 nanoseconds at 1000 pps	-37 dB	
2500 pps	-33 dB	
4000 pps	-31 dB	
500 nanoseconds at 1000 pps		-33 dB
4000 pps		-30 dB

A.2.5 Frequency

The frequency of the transmitted pulse was measured by using the test setup shown in Figure A-3 and entered into the daily check list.

FIGURE A-3. Test setup for frequency check.

A.2.6 Mean Discernible Signal (MDS)

The test setup for this check is illustrated in Figure A-4. With this setup, a measurement was made of the minimum signal generator pulse sensed by the receiver. An rf pulse was inserted from the signal generator into the antenna port of the receiver. The signal generator frequency was varied for maximum video level as observed on an A-scope presentation. The level of the rf pulse was reduced until the video pulse was barely discernible with the video noise. This level was then entered into the daily check list. The value specified was -95 dBm.

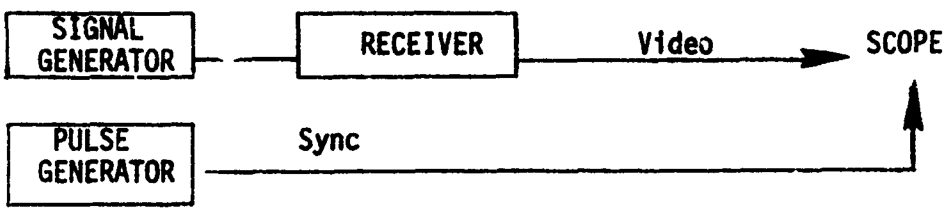

FIGURE A-4. Test setup for MDS check.

A.2.7 Pulse Jitter

The test setup for this check is illustrated in Figure A-1. An observation was made of the trailing and leading edges of the pulse for jitter. Any jitter observed was measured at the 3-dB point of the pulse and recorded in the daily check list.

A.3 MEASUREMENTS

Tables A-2 and A-3 present the values obtained in the daily checks of the AIL and HAR radars.

TABLE A-2. Summary of HAR radar parameters measurements.

Date (February 1973)	PRF (pps)	Pulse Width (nanoseconds)	Peak Power (dBm)	MDS (dBm)	Frequency (Megahertz)	VSWR (dB)
6	4000	55	+71.3	-89.1		
	1000	560	+68.6	-92.1	9500	
7	4000	55	+67.9			
	1000	560	+65.3	-95.8	9500	
8	4000	55				
	1000	550		-94.8	9502	13.5
9	4000	50	+69.0			
	1000	500	+69.6	-92.8	9505	18.8
12	4000	45	+73.0			
	1000	600	+67.4	-94.8	9502	19.0
14	4000	55	+73.3			
	1000	540	+70.8	-94.8	9502	13.0
15	4000	55	+73.3			
	1000	560	+70.8	-94.8	9502	12.0
16	4000	50	+76.8			
	1000	500		-95.0	9502	20.0
Mean Values	4000	52.5	+72.2			
	1000	546	+69.15	-93.4		

* A very dry day without rain.

TABLE A-3. Summary of AIL radar parameter measurements.

Date (February 1973)	PRF (pps)	Pulse Width (nanoseconds)	Peak Power (dBm)	MDS (dBm)	Frequency (Megahertz)
6	4000	42	+74.6	-93	9437
	4000	205	+75.7		
	2500	42	+75.6		
	2500	205	+77		
	1000	42	+75.7		
	1000	205	+77.2		
7	4000	50	+74	-95	9438
	4000	200	+75.7		
	2500	50	+74.4		
	2500	200	+76.9		
	1000	50	+75.4		
	1000	200	+77.0		
8	4000	43	+76.1	-96	94[illegible]8
	4000	200	+77.3		
	2500	43	+76.4		
	2500	200	+78.5		
	1000	43	+77.5		
	1000	200	+75.2		
9	4000	45	+76.4	-93	9438
	4000	205	+78.6		
	2500	45	+76.3		
	2500	205	+79.5		
	1000	45	+77.7		
	1000	205	+79		
12	4000	45	+75.5	-95	9438
	4000	200	+77.4		
	2500	45	+75.6		
	2500	200	+78.5		
	1000	45	+76.8		
	1000	200	+79		

TABLE A-3 (Continued)

Date (February 1973)	PRF (pps)	Pulse Width (nanoseconds)	Peak Power (dBm)	MDS (dBm)	Frequency (Megahertz)
14	4000	50		-93	9438
	4000	200			
	2500	50			
	2500	200			
	1000	50			
	1000	200			
15	4000	45	+75.7	-93	9435
	4000	200	+77		
	2500	45	+76		
	2500	200	+78.4		
	1000	45	+77.5		
	1000	200	+77.2		
16	4000	50	+76.4	-93	9438
	4000	200	+78		
	2500	50	+76.2		
	2500	200	+79.4		
	1000	50	+78.2		
	1000	200	+79		
Mean Values	4000	46.3	+75.6	-93.9	9437.5
	4000	201	+77.2		
	2500	46.3	+75.8		
	2500	201	+78.4		
	1000	46.3	+77.1		
	1000	201	+77.8		

Reference

(a) U. S. Coast Guard Project 732222.01, Test Plan dated January 1973, "San Francisco Harbor Comparison Tests of the Raytheon 1605 Harbor Advisory Radar With the AIL Vessel Traffic System Radar", prepared by the Applied Physics Laboratory/The Johns Hopkins University for the Commandant (GDET), U. S. Coast Guard.

END